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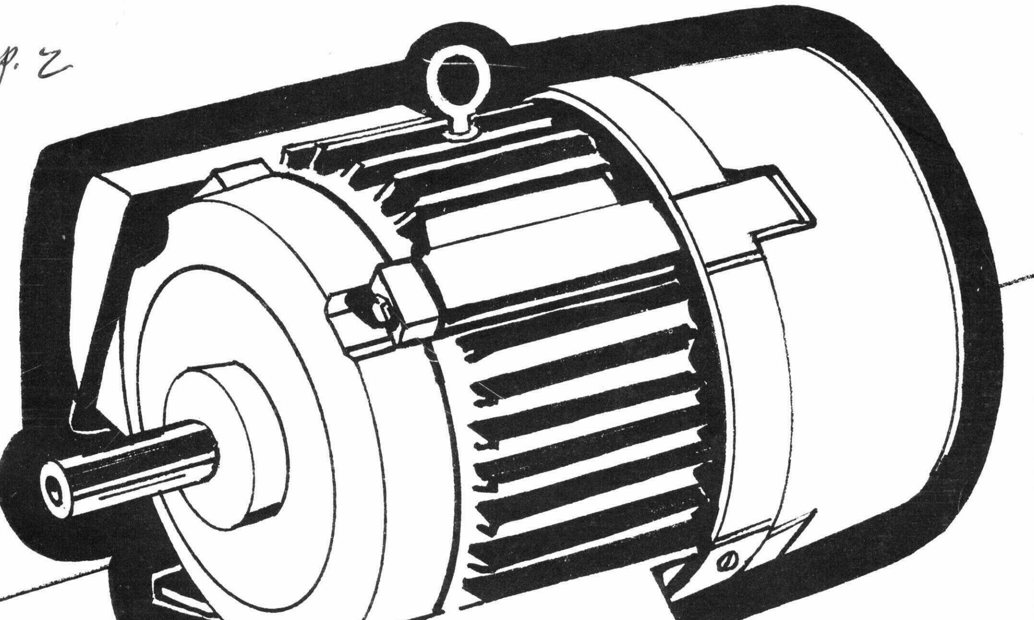
SELECTING AND USING ELECTRIC MOTORS



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SELECTING AND USING ELECTRIC MOTORS

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Electric motors are an efficient, compact, and dependable source of power. Effective use, however, requires the selection of the best type for a particular job, proper installation, and the use of suitable controls for the operation and protection of the motor.

Alternating-current motors designed to operate on 115 or 230 volts, 60 hertz (cycles), and single-phase service are generally being used on farms. However, three-phase motors, particularly in the larger horsepower ratings, are becoming more common as three-phase power or the use of phase converters makes their operation possible on rural power lines.

Special-purpose motors are sometimes installed by manufacturers as an integral part of their equipment. These motors usually have characteristics that are not suitable for general-purpose use and are not considered in this bulletin.

SINGLE-PHASE MOTORS

The seven general types of single-phase, alternating current (a.c.) motors found on the farm are as follows:

1. Split-Phase (SP)
2. Capacitor
   a. Capacitor Start (CS-IR) (Capacitor Start-Induction Run)
   b. Two-Value Capacitor (CS-CR) (Capacitor Start-Capacitor Run)
   c. Permanent-Split Capacitor (PSC)
3. Wound-Rotor
   a. Repulsion-Start (RS)
   b. Repulsion-Induction (RI)
   c. Repulsion (R)
4. Shaded-Pole
5. Universal or Series (UNIV)
6. Synchronous
7. Soft Start (SS)

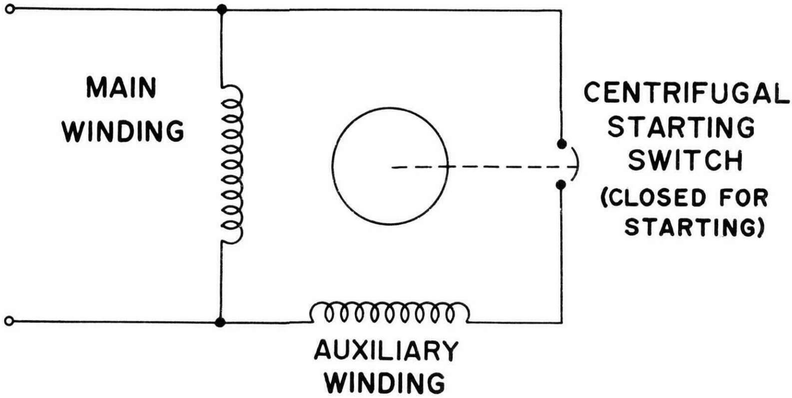
Three-phase motors that are operated on single-phase power through phase converters may also be used for single-phase applications.

Motor types differ primarily in the amount of starting torque de-

veloped and in their starting-current requirements. The type to use depends on the starting requirements of the equipment to be driven and the maximum current that may be drawn from the single-phase power service. Table 1 lists the important characteristics of each type of single-phase motor.

Split-Phase Motors (SP)

Split-phase motors are inexpensive and widely used fractional horsepower motors (fig. 1). They



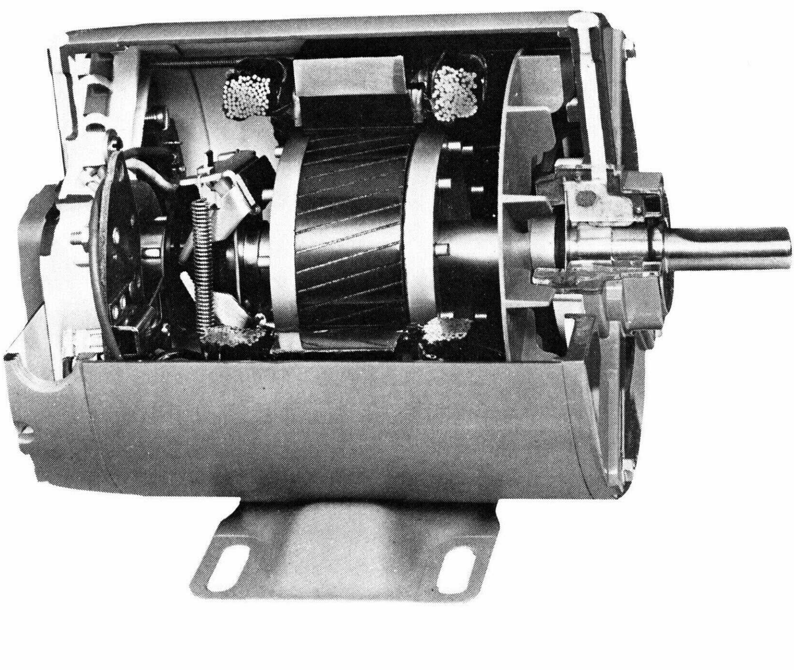


FIGURE 1.—The split-phase motor is a low-cost unit suitable for handling easy-starting loads.

Table 1.—Types of single-phase motors and their characteristics

Type	Horsepower ranges	Load-starting ability	Starting current	Characteristics	Electrically reversible	Typical uses
Split-phase	1/20 to ½	Easy starting loads. Develops 150 percent of full-load torque.	High; five to seven times full-load current.	Inexpensive, simple construction. Small for a given motor power. Nearly constant speed with a varying load.	Yes.	Fans, centrifugal pumps; loads that increase as speed increases.
Capacitor-start	1/8 to 10	Hard starting loads. Develops 350 to 400 percent of full-load torque.	Medium, three to six times full-load current.	Simple construction, long service. Good general-purpose motor suitable for most jobs. Nearly constant speed with a varying load.	Yes.	Compressors, grain augers, conveyors, pumps. Specifically designed capacitor motors are suitable for silo unloaders and barn cleaners.
Two-value capacitor	2 to 20	Hard starting loads. Develops 350 to 450 percent of full-load torque.	Medium, three to five times full-load current.	Simple construction, long service, with minimum maintenance. Requires more space to accommodate larger capacitor. Low line current. Nearly constant speed with a varying load.	Yes.	Conveyors, barn cleaners, elevators, silo unloaders.

Table 1.—Types of single-phase motors and their characteristics—continued

Type	Horsepower ranges	Load-starting ability	Starting current	Characteristics	Electrically reversible	Typical uses
Permanent-split capacitor	1/20 to 1	Easy starting loads. Develops 150 percent of full-load torque.	Low, two to four times full-load current.	Inexpensive, simple construction. Has no start winding switch. Speed can be reduced by lowering the voltage for fans and similar units.	Yes.	Fans and blowers.
Shaded pole	1/250 to ½	Easy starting loads.	Medium.	Inexpensive, moderate efficiency, for light duty.	No.	Small blowers, fans, small appliances.
Wound-rotor (Repulsion)	1/6 to 10	Very hard starting loads. Develops 350 to 400 percent of full-load torque.	Low, two to four times full-load current.	Larger than equivalent size split-phase or capacitor motor. Running current varies only slightly with load.	No. Reversed by brush ring re-adjustment	Conveyors, drag burr mills, deep-well pumps, hoists, silo unloaders, bucket elevators.
Universal or series	1/150 to 2	Hard starting loads. Develops 350 to 450 percent of full-load torque.	High.	High speed, small size for a given horsepower. Usually directly connected to load. Speed changes with load variations.	Yes, some types.	Portable tools, kitchen appliances.

Table 1.—Types of single-phase motors and their characteristics—continued

Type	Horsepower ranges	Load-starting ability	Starting current	Characteristics	Electrically reversible	Typical uses
Synchronous	Very small, fractional	N/A[1]	N/A	Constant speed.	N/A	Clocks, timers.
Soft-start	10 to 75	Easy starting loads.	Low, 1.5 to 2 times full-load current.	Excellent for large loads requiring low starting torque.	Yes.	Crop driers, forage blowers, irrigation pumps, manure agitators.

[1]N/A = not applicable.

are only suitable for handling easy starting loads such as ventilating fans because of their low starting torque. They are rarely used in sizes larger than one-half horsepower because of their relatively high starting currents. Generally their use is limited to applications where their low cost is more important than their low torque and high starting currents.

Power is applied to a starting, or auxiliary, winding through a starting switch during the starting period. The direction of rotation can be changed by reversing the line connections to the starting, or auxiliary, winding.

Capacitor Motors

Capacitor-Start Motors (CS-IR)

This is a popular type for general use. Capacitor-start (capacitor-start-induction run) motors are similar in design to split-phase motors, with one important difference—a capacitor is placed in series with the auxiliary winding (fig. 2). The capacitor gives

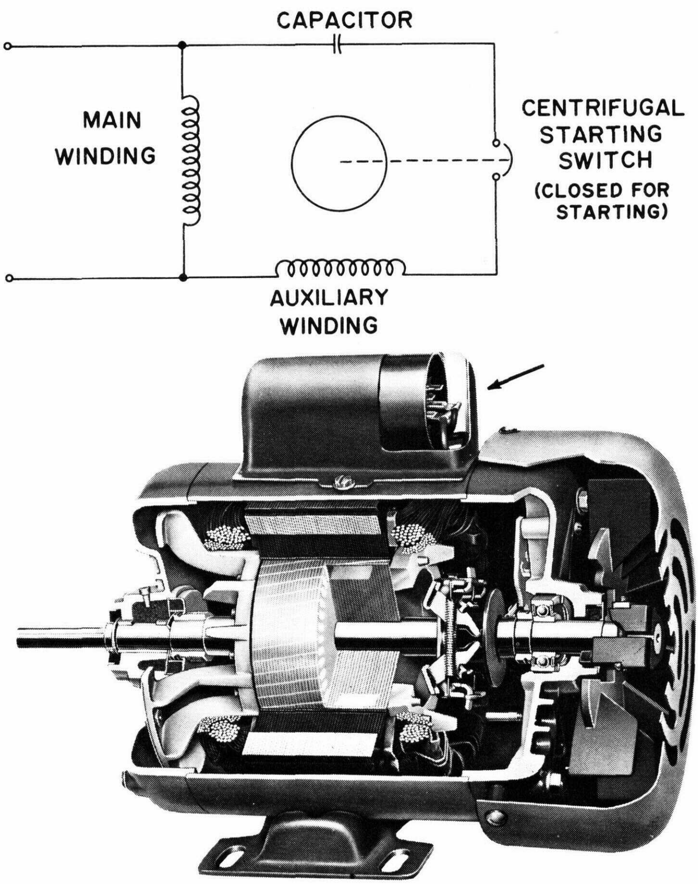


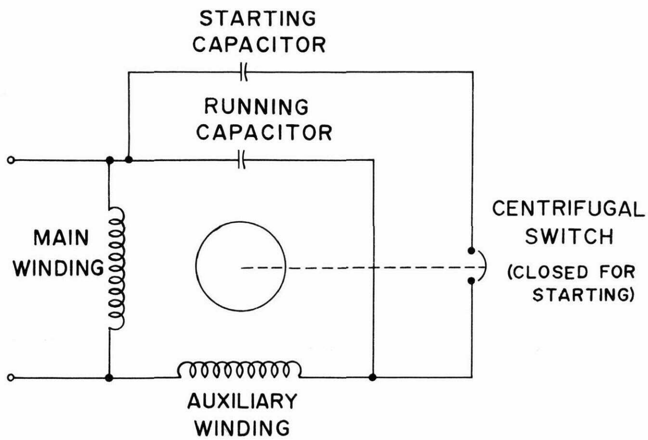
FIGURE 2.—The capacitor-start motor has medium starting torque and is one of the most used general-purpose motors. Arrow points to capacitor.

the motor up to twice the starting torque of a split-phase motor with about one-third less current requirement. The capacitor-start motor is electrically reversible in the same manner as a split-phase motor. Line connections to the starting winding are interchanged to reverse the direction of rotation.

Starting torque of capacitor motors may be reduced when they operate at very low temperatures because the capacitance of the electrolytic starting capacitor is less at low temperatures. This factor should be considered when selecting the size of a capacitor-start motor to be used for hard starting loads in cold weather.

Two-Value Capacitor Motors (CS-CR)

Two-value capacitor (capacitor start-capacitor run) motors are similar to capacitor-start motors (fig. 3). CS-CR motors use the



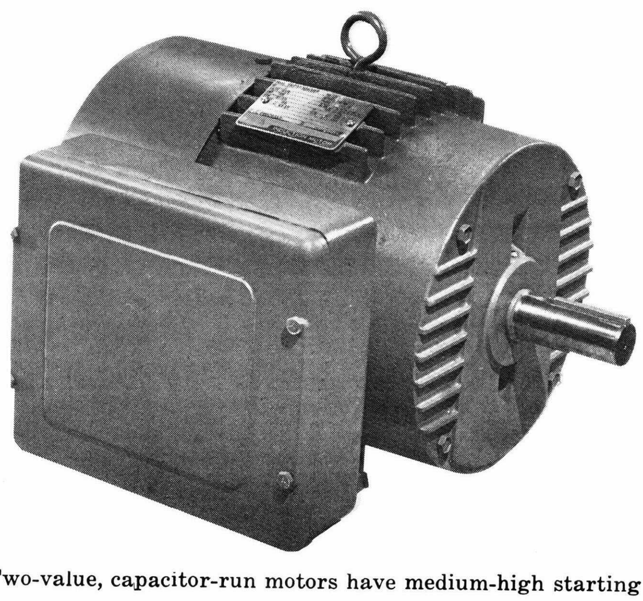


FIGURE 3.—Two-value, capacitor-run motors have medium-high starting torque.

same type of starting circuit as CS-IR motors, but a small capacitor remains in series with the auxiliary winding during running. This capacitor gives greater efficiency of operation by lowering the amount of line current required to run the motor.

These motors have slightly higher starting torque than capacitor-start motors and, therefore, can handle more difficult starting loads. The starting current requirement is about the same for both CS-IR and CS-CR types. Direction of rotation can be reversed electrically.

Permanent-Split Capacitor Motors (PSC)

Permanent-split capacitor motors are similar to capacitor-start motors except that the same value of capacitance is used for both starting and running conditions (fig. 4). Starting torque is much lower than that for capacitor-start motors and the breakdown

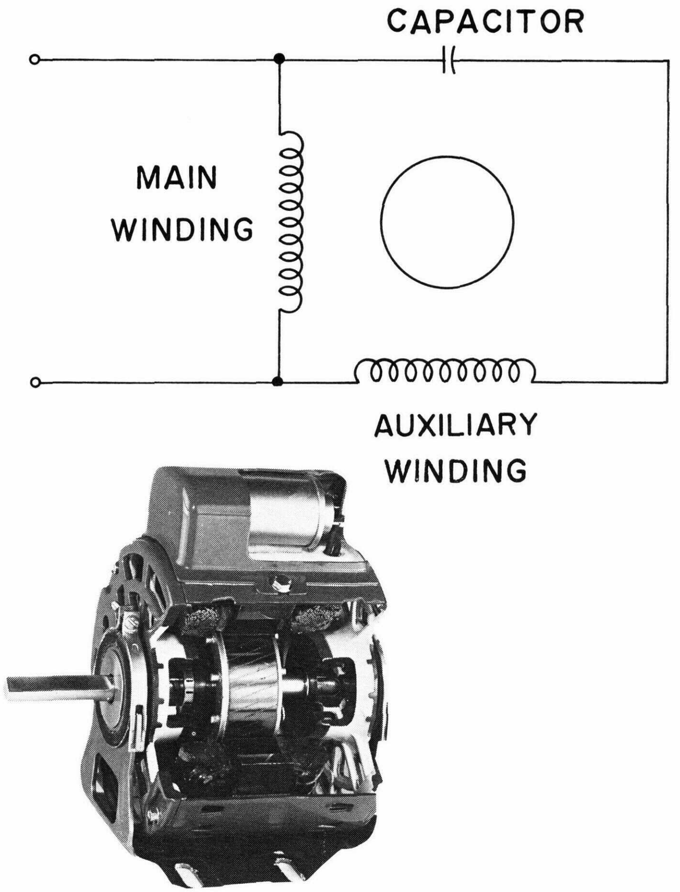


FIGURE 4.—The permanent-split capacitor motor is a low-cost design suited for fan and blower operation.

torque is suitable for loads that require load peaks no greater than normal load torque, such as fans and blowers.

No starting mechanism is used on PSC motors, therefore, they are adaptable to variable speed control and can be operated at reduced speeds (below design speed) by lowering the effective supply voltage. A PSC motor should not be operated at a speed less than that at which torque breakdown occurs. With a standard low-slip motor, torque breakdown occurs at about 75 percent of the motor's synchronous speed. With a high-slip design, torque breakdown occurs at less than 75 percent of the synchronous speed.

Motor current much higher than normal will be drawn if the PSC motor is operated at a speed lower than that at which torque breakdown occurs.

Wound-Rotor Motors

Wound-rotor, or repulsion, motors are single-phase motors that have a stator winding arranged for connection to a source of power and a rotor winding connected to a commutator. The running current for wound-rotor motors varies little with variations in load, and heavy starting loads can be handled with low starting current. These motors are more expensive than split-phase or capacitor motors and require more maintenance because of brush and commutator wear. The three general subtypes of wound-rotor motors are discussed in this section.

Repulsion-Start Induction Motors (RS)

This kind of motor starts as a repulsion motor but operates as an induction motor with speed characteristics similar to a capacitor-start motor. Repulsion-start induction motors are the most common type among the wound-rotor motors. They have a rotor similar to the kind found in all wound-rotor motors (fig. 5). At a predetermined speed, the rotor winding is short-circuited or otherwise connected to give the equivalent of a squirrel-cage winding.

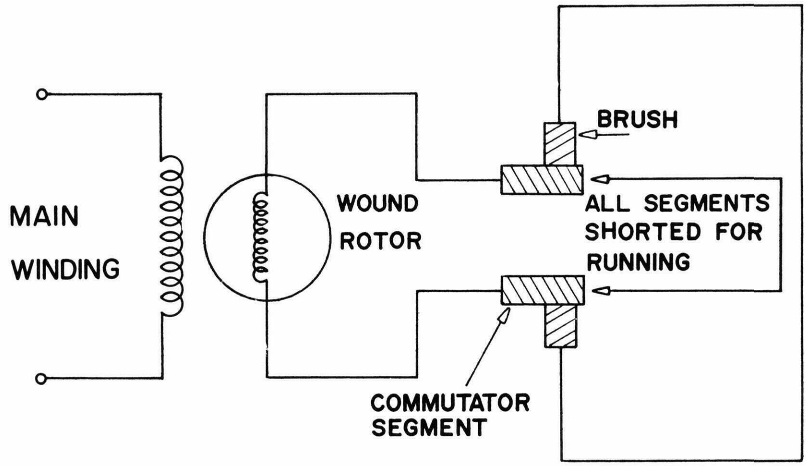
Repulsion-Induction Motors (RI)

A repulsion-induction motor is a form of wound-rotor motor that has a squirrel-cage winding in the rotor in addition to the repulsion, or wound-rotor, winding. This motor may be either constant-speed or varying-speed, depending on design, and it is capable of starting very difficult loads with less voltage than other general-purpose motors.

Repulsion Motors (R)

This type motor carries the name often applied to all single-phase, wound-rotor motors. Brushes on the commutator are short-circuited and placed so that the magnetic axis of the rotor winding is inclined to the magnetic axis of the stator. This type motor has varying speed and is sometimes referred to as a variable-speed motor. Speed of this motor is controlled by the load.

The repulsion motor starts and runs as a repulsion motor. Brushes do not lift and the commutator is not shorted. Output torque and motor speed for a given load are controlled by the brush setting. The no-load speed of this type motor is above synchronous speed.



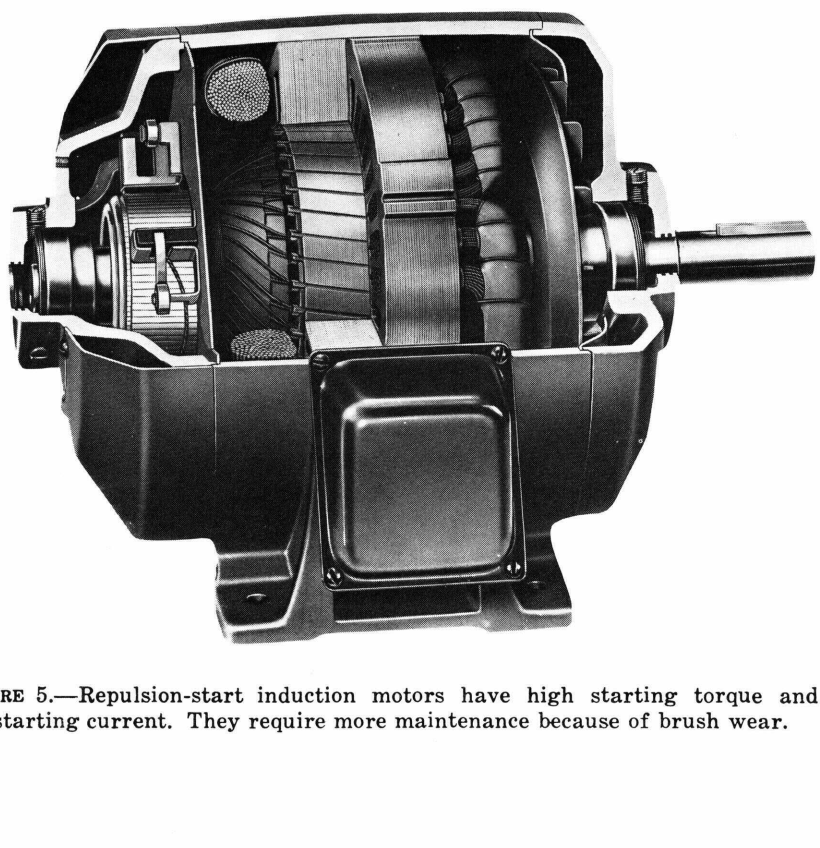


FIGURE 5.—Repulsion-start induction motors have high starting torque and low starting current. They require more maintenance because of brush wear.

Shaded-Pole Motors

Shaded-pole motors are low-cost, low-starting-torque motors that are simply constructed. A short-circuiting ring of copper, or other conductor, in a slot in each pole face provides the electrical characteristics that enable the motor to start (fig. 6). The low efficiencies of these motors in addition to their low starting torques limit their use to small size loads.

Universal or Series Motors (UNIV)

The universal or series motor is a high-speed motor that will operate on either alternating or direct current (fig. 7). It is usually a special-purpose motor, often built into portable equipment such as drills, grinders, sanders, sprayers, vacuum cleaners, and food mixers. The advantages of this type of motor include high starting torque, high power-to-size ratio, and rapid acceleration of the load to speed.

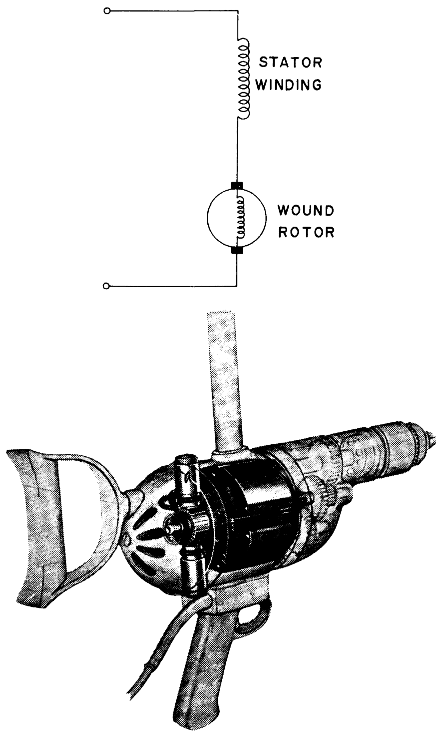


FIGURE 7. A universal motor used in an electric drill.

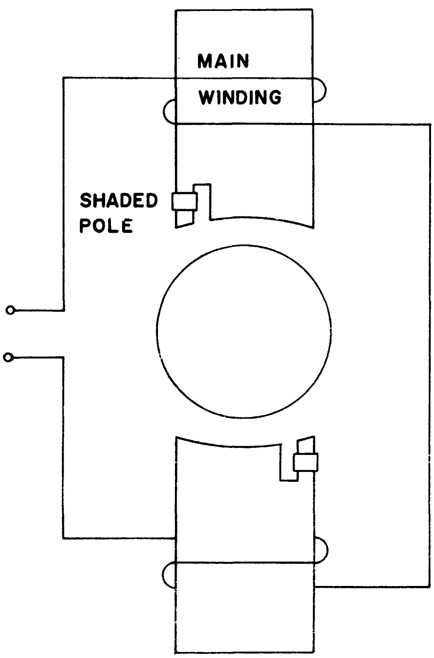


FIGURE 6. Diagram of a shaded-pole motor.

The operating speed of these motors depends on the load. They do not operate at a constant speed, but run as fast as the load permits. If not loaded, they will overspeed, which may damage the motor.

Synchronous Motors

Synchronous motors are constant-speed motors that are sel-

dom used on a farm except in clocks and timers. A most important characteristic is that their output speed is very exact. Synchronous motor speed is determined by the design and the a.c. line voltage frequency.

Soft-Start Motors (SS)

In large integral horsepower motors, starting currents may be high enough to restrict the use of large motor sizes on available single-phase power lines. Special single-phase, soft-start motors are available that have a reduced starting current as low as one and one-half to two times normal running current.

The lower starting currents in soft-start motors are usually obtained by suitable switching of the motor windings, such as using two windings placed in series for starting and in parallel for running. By reducing the high starting current, large motors may be operated on single-phase power lines. The reduced starting current results in lower starting torque (50 to 90 percent of full-load torque) than conventional single-phase motors. Therefore, this type motor is best suited to easy starting loads such as crop drier fans, forage blowers, manure agitators, or saws.

THREE-PHASE MOTORS

The rotating magnetic field provided by three-phase a.c. power permits a simple and low-cost means of constructing an electric motor. In general-purpose use, three-phase motors require no auxiliary winding switch and no starting or running capacitors. Therefore, these major sources of failure in split-phase and capacitor-start, single-phase motors are eliminated.

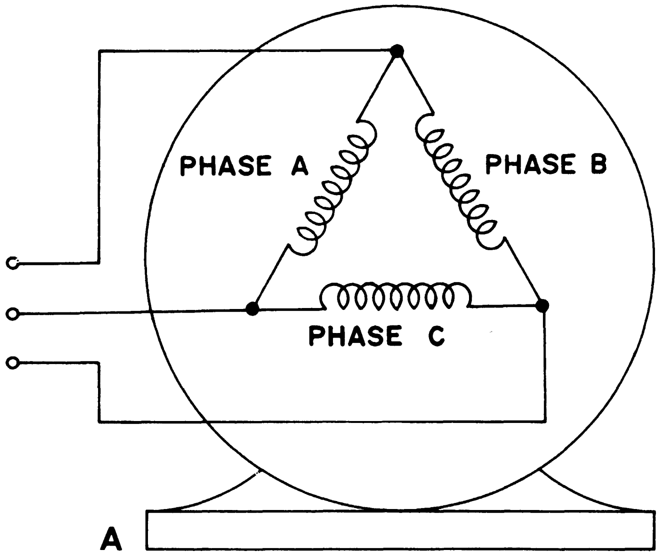
Three-phase motors may be made for either a wye (Y) or delta (△) connection (fig. 8). For balanced phase voltages, both types have similar performance. An important consideration in the application of either type is that the proper connections be made to the motor windings.

The horsepower of three-phase motors ranges from one-half to 400 and the starting current required is low to medium, about three to four times full-load current. Some typical uses of three-phase motors are for crop driers, elevators, conveyors, irrigation pumps, and hoists.

Three-phase motors can be easily reversed electrically, making them useful for applications involving control of direction or remote positioning. Several different speed-torque characteristics are also available so that the motor performance can be matched to a particular use.

Normally, the speed-torque characteristics and the rotor impedance are fixed. Motors are available, however, that have variable speed-torque characteristics in designs using a wound

rotor and an external variable rheostat connected to the rotor by slip rings. The wound-rotor type is considerably more expensive than fixed rotor types and requires more maintenance.



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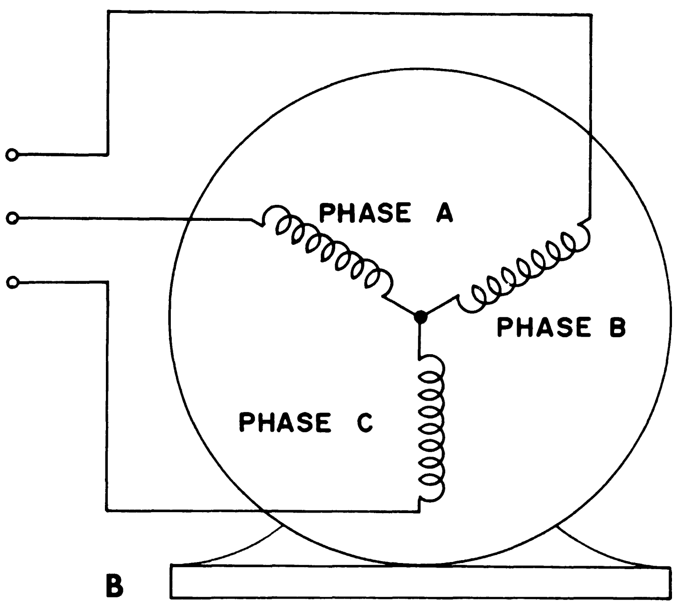


B

FIGURE 8.—Diagrams of three-phase motor electrical connections. A, Delta (△); B, Wye (Y).

VARIABLE-SPEED MOTORS

For some farm applications such as ventilating fans, feed handling equipment, or tools, variable-speed drives may be needed. Mechanical speed control often is used to obtain the desired output speed. However, variable-speed motors are more desirable in many cases, particularly for use in automatic control systems.

Variable-speed motors are available in the following basic types:

1. Adjustable-voltage d.c.
2. Adjustable-voltage a.c.
3. Adjustable-frequency a.c.
4. Wound-rotor motors

The adjustable-voltage a.c. system is the only type generally used on farms at the present time.

For the control of voltage applied to a motor, variable transformers, series resistors, or solid-state power control devices may be used. Solid-state switches called thyristors or silicon-controlled rectifiers (SCR's) are often used to control the portion of each cycle of the a.c. voltage that power is allowed to pass.

Since SCR's pass current in only one direction, two such devices are required to pass both halves of the a.c. cycle. A similar device, the triac, will pass current in both directions and is commonly used. Either SCR's or triacs are available in packaged, solid-state, motor-speed controls of the type shown in figure 9 to vary the voltage to the motor.

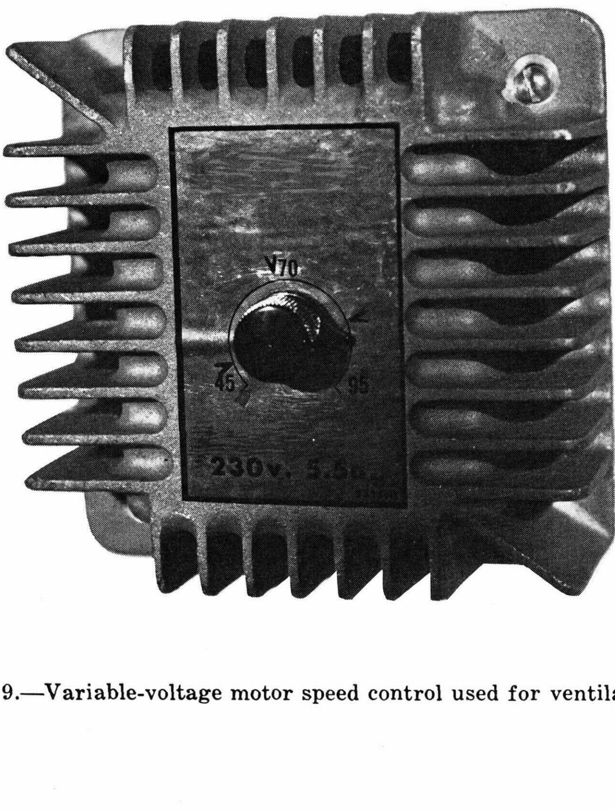


FIGURE 9.—Variable-voltage motor speed control used for ventilating fans.

Speed control is obtained by varying the time period that the SCR or triac is turned on, which controls the effective voltage applied to the motor.

The design of the motor is important in obtaining speed control over a wide range and should be suitable for variable-voltage applications. It is also important that a motor used with variable-voltage motor speed controls be of a type that has no starting mechanism such as the universal, shaded-pole, or permanent split-capacitor motor.

Several precautions that should be observed in the operation of variable-speed motors are as follows:

1. The lowest speed setting should be limited to provide proper bearing lubrication.

2. The speed control used should provide sufficient voltage to start the motor under load at low speed settings.

3. The lowest speed setting should be high enough to provide sufficient ventilation to prevent overheating of the motor.

Because of the varied possibilities of variable-speed motors, selection and application of such motors should be done in consultation with the equipment manufacturer and the local power supplier.

PHASE CONVERTERS

Whenever it is desirable to operate three-phase motors but three-phase power is not available, phase converters make it possible to operate from single-phase power lines. It is essential, however, that the combination of converter and three-phase motor is properly selected and applied. Combinations of phase converters and three-phase motors are being used to successfully operate many types of farm loads, such as crop driers, grain handling systems, irrigation pumps, and animal feeding systems.

The two general types of phase converters that are available are static and rotary. Each type offers advantages for specific kinds of motor loads. Proper choice of a phase converter type is determined by the motor loads that must be run.

Static converters with no moving parts other than relays are available in two general types, capacitor and autotransformer capacitor. Both types are generally used with a single motor. The full-load capacity of the three-phase motor may need to be reduced, depending on the exact type of static converter used. Care must be taken to see that motor loading is such that the currents in each phase do not exceed motor nameplate rating and damage the motor. Also, motors may run rough if they are operated at loads substantially less than those at which the phase converter was balanced.

Rotary converters have a ro-

tating unit and a capacitor bank. Rotary converters are more suitable for multimotor use than static converters and generally will operate any combination of motors up to approximately twice their rating for the maximum motor size that they will start.

For both types of converters, the starting torque of three-phase motors may be reduced to 50 to 80 percent of normal. The exact amount of reduction depends on the phase converter design, and this factor must be taken into account when selecting motor sizes.

If the phase voltages and currents from the converter to the motor are approximately balanced, motor starting currents are reduced at the same time that motor starting torque is reduced. This permits the use of a converter-operated three-phase motor that has more horsepower than a standard single-phase motor on a single-phase line. Therefore, converter-motor combinations are sometimes used as the equivalent of soft-start motors.

Proper phase converter selection, installation, and wiring are essential for satisfactory operation. Overcurrent protection for the motor should be used in all three motor leads. For more information on phase converters, see Farmers' Bulletin 2252, "Phase Converters for Operation of Three-Phase Motors from Single-Phase Power."[1]

MOTOR SELECTION

The choice of the proper electric motor depends primarily on the electrical service available, the size and type of load, and the environmental conditions under which the motor will operate.

Electrical Service

Single-Phase

Farm electrical service is usually 120 or 240 volts, 60 hertz, and single-phase for operation of motors and equipment rated at 115 or 230 volts. Single-phase motors up to and including one horsepower can be operated on 115 volts. Generally, however, because of the large currents drawn by motors over one-half horsepower, particularly at starting, motor sizes larger than one-half horsepower should be operated on 230 volts.

Three-Phase

Three-phase power is available for some farms. General-purpose, three-phase motors in sizes above two horsepower may be more readily available and are generally less expensive than single-phase motors. Both wye and delta three-phase systems are common

[1] For a free copy of this publication see your county agricultural agent or write to Office of Communication, U.S. Department of Agriculture, Washington, D. C. 20250. Send your request on a post card. Include your ZIP Code number.

on farms. Figure 10 illustrates these two electrical systems and the phase-to-phase voltages as well as the phase-to-neutral voltages. It is important that a three-phase motor be chosen to match the phase-to-phase voltage of the electrical system available.

Three-phase motors can also be operated on single-phase power. This is discussed in the section on phase converters.

Effects of Voltage and Frequency on Motor Performance

For proper performance of an electric motor, the supply voltage and frequency at the motor terminals must match the values specified by the manufacturer as closely as possible. Motor performance usually is determined at rated voltage and frequency. Satisfactory performance generally is obtained over a range of plus or minus 10 percent from rated voltage and plus or minus 5 percent from rated frequency.

If you allow the applied voltage or frequency to vary from the nominal values specified on the motor nameplate, there will be changes in the motor torque from the values that are given at rated voltage and frequency. These changes in performance occur because torque developed by the motor is approximately proportional to the square of the voltage and inversely proportional to the square of the frequency.

The successful operation of a motor under running conditions, with the voltage and frequency variations within the allowable range, does not necessarily mean that the motor will start and accelerate the load under these conditions. Limiting values of voltage and frequency at which a motor will start and accelerate a load to running speed depend on

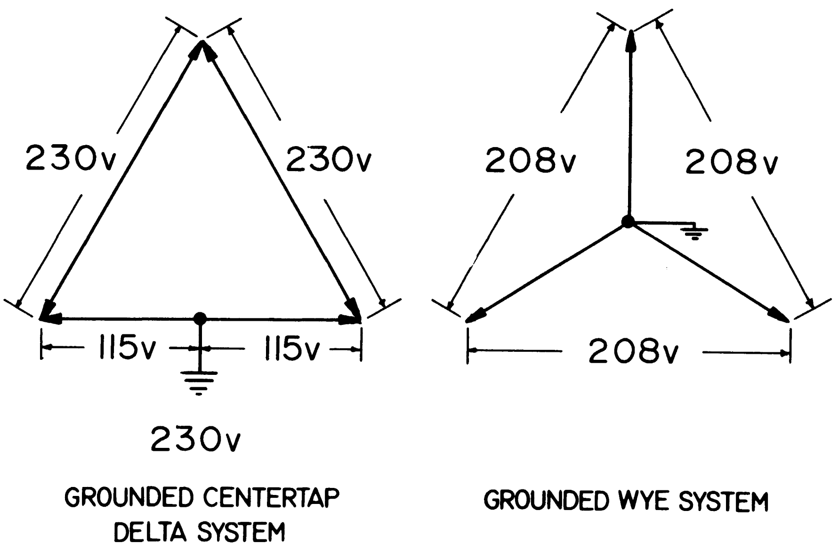


FIGURE 10.—Electrical systems of the Delta and Wye types showing phase-to-phase and phase-to-neutral voltages.

the margin between the speed-torque curve of the motor at rated voltage and frequency and the speed-torque curve of the load under starting conditions.

Frequency variation is generally no problem, except for possible operation by standby power units. Low voltage from inadequate wiring or other causes, however, can cause severe problems because motor starting torque may be too low to start and accelerate the load. The section on wiring gives recommended minimum sizes of conductors.

Proper motor voltage is, therefore, particularly important for hard starting loads; at 80 percent of its rated voltage, a motor develops only 64 percent of the torque that is developed at nameplate voltage rating.

Motor Torque Characteristics

An electric motor is simply a device for converting electrical power into mechanical power. Therefore, after the type of power source has been determined, the next step is to determine the motor size required for the load.

To start the load, a certain amount of turning force is required. The motor shaft turning force, or torque, is the turning force available from the motor shaft. A load such as a fan starts easily, and the shaft can be turned by hand (low starting torque). A load such as a filled grain auger starts much harder (high starting torque), and a wrench is needed to rotate the shaft. An electric motor must be selected that will provide the starting torque required by the load as well as the torque necessary to bring the load to operating speed.

When the load is running, a given amount of turning force is required for rotating the load at the desired speed. This power that the motor must put out (horsepower) is proportional to the shaft speed and torque required. Thus, the horsepower required to turn the load determines the size of motor that must be selected. If too small a motor is selected, it will be overloaded and have a short life.

Farm equipment varies widely in the amount of power required for starting. For example, fans, bench saws, and grindstones are easy to start. Split-phase motors, which have low starting torque, will satisfactorily operate this equipment. Reciprocating compressors, auger conveyors, and vacuum pumps are harder to start and require motors with higher starting torque, such as the capacitor-start type. Bucket elevators, barn cleaners, silo unloaders, or similar equipment are very hard to start and require motors with high starting torque, such as two-value capacitor or repulsion types.

The torque characteristics of a load that a motor is required to start and run are therefore important in the choice of a motor. Typical torque characteristics of a load and a motor are shown in figure 11. Motor torque must exceed load torque requirements

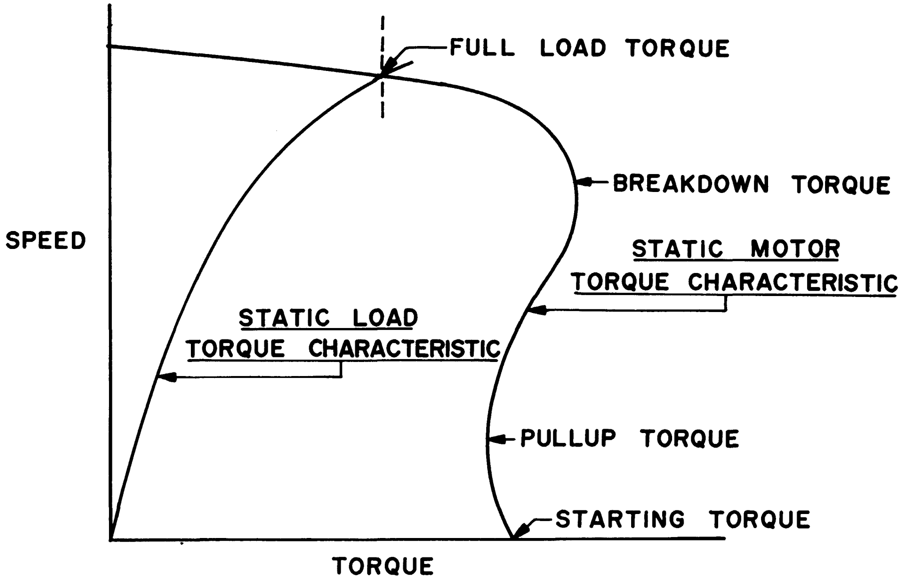


FIGURE 11.—Typical motor and load torque characteristics.

over the entire range of speed if the motor is to properly start and bring the load to operating speed. The motor torque characteristics that are important in matching a motor to a load are defined as follows.

Full-load torque is the turning force that the motor will deliver continuously at rated voltage and speed without exceeding its temperature rating. Full-load torque usually determines the basic rating and therefore size of the motor that must be used.

Starting torque (locked rotor) is the amount of torque that the motor has available at zero speed. Starting torque is important and may dictate the type of motor that must be used.

Breakdown torque is the maximum torque that a motor develops at rated voltage without an abrupt drop in speed. Breakdown torque must be considered in relation to peak intermittent loads that may be encountered.

Pull-up torque is the minimum torque that is developed by the motor during the period of acceleration from zero speed to the speed at which breakdown torque occurs. Pull-up torque is generally of minor importance but must be adequate to accelerate a load up to its operating speed.

Motor Loading

The life of an electric motor is reduced if the motor is overloaded for extended periods. Overload is indicated when the current is above the nameplate rating. One method of checking for motor overload is to measure the current drawn by the motor. A clamp-on

ammeter may be used for this purpose as shown in figure 12.

Each of the conductors carrying power to the motor is passed through the clamp-on ammeter loop individually to determine the current of the motor under load conditions. Currents should be approximately equal and within the motor nameplate rating for both leads of a single-phase motor and for all three leads of a three-phase motor.

If motor current exceeds the motor nameplate current rating, the motor is most likely overloaded and motor temperature will rise above the rated value. Unless the load is of short duration or the cooling air temperature is below 40° C. (104° F.), motor life will be shortened. The load on the motor should be adjusted so that the current drawn by the motor is within the nameplate rating to obtain normal motor life.

Temperature

Once the required motor torque characteristics are determined, motor temperature ratings should be considered. Both motor insulation and bearings have definite temperature limitations for long successful operation. Generally, however, bearing temperature limits will be met if insulation temperature is kept within the permitted range.

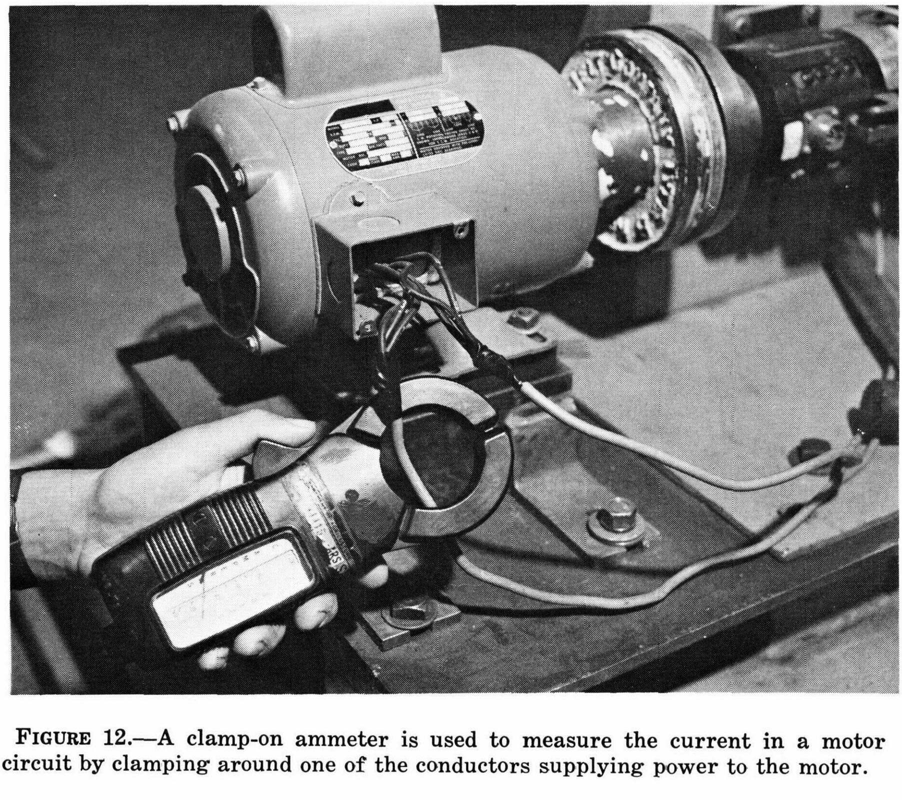


FIGURE 12.—A clamp-on ammeter is used to measure the current in a motor circuit by clamping around one of the conductors supplying power to the motor.

Four insulation systems are available for small induction motors. They are as follows.

System	*Maximum hot spot continuous temperature*
Class A	105° C. (221° F.)
Class B	130° C. (266° F.)
Class F	155° C. (311° F.)
Class H	180° C. (356° F.)

Temperature limits are established by Underwriters' Laboratories to protect against fire hazards and by the National Electrical Manufacturers Association (NEMA) to assure adequate motor life. Nameplate data generally give the permissible temperature rise above the ambient air or the maximum ambient temperature for motor operation that will keep the hot spot temperature of the motor within the specified value for the insulation system used. Normal maximum ambient temperature is 40° C (104° F.) for most motor ratings.

Farm equipment manufacturers usually recommend the type and size of electric motor needed to operate their equipment. Their recommendations are generally based on the starting, pull-up, breakdown, and running torques required under normal operating conditions and serve as a basis for motor selection. For unusual conditions, consult the equipment manufacturer or power supplier, or both.

Operating Conditions

Electric motors are often operated under adverse conditions where there is dust, dirt, or moisture or where there are explosive mixtures of gas or dust such as in feed or flour mills. Motors are available with different types of enclosures, or housings, for use under specific operating conditions. Selecting the proper type of enclosure is important for the protection of the motor and for safe operation.

Enclosures

Two general types of enclosures are available, open and totally enclosed.

An open motor is one that has ventilating openings that permit the passage of external cooling air over and around the windings of the machine. Open enclosures may be drip-proof or splash-proof (fig 13).

A drip-proof enclosure protects a motor from liquids or solids falling zero to 15 degrees downward from vertical. It is designed for indoor use where the air is fairly clean and where there is little danger of splashing liquid.

A splash-proof enclosure protects the motor from liquids or particles that strike the enclosure at angles not greater than 100 degrees downward from vertical. Such motors may be used outdoors but must be protected from the weather (fig. 14).

Totally enclosed motors are those where the enclosure prevents the free exchange of air between the inside and outside of the case but does not make the case completely airtight. They may be cooled by a fan (totally enclosed fan-cooled, TEFC), or by

direct radiation and convection of heat through the case (totally enclosed, nonventilated). See figure 15.

Totally enclosed motors are also available in explosion-proof, dust-ignition-proof, and water-proof designs for operation under dirty

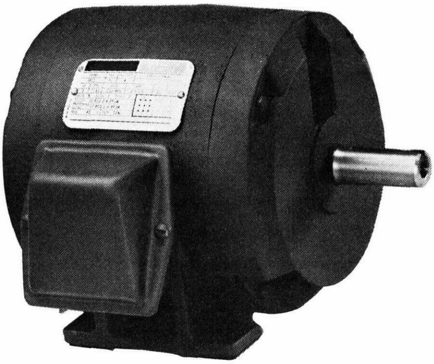


FIGURE 13.—Drip-proof (left) and splash-proof (right) motors draw cooling air through the motor windings. The splash-proof motor has greater protection against the entry of splashing liquids.

FIGURE 14.—Splash-proof motors installed outside should be protected from the weather by a suitable covering. The motor drive is covered as a safety precaution.

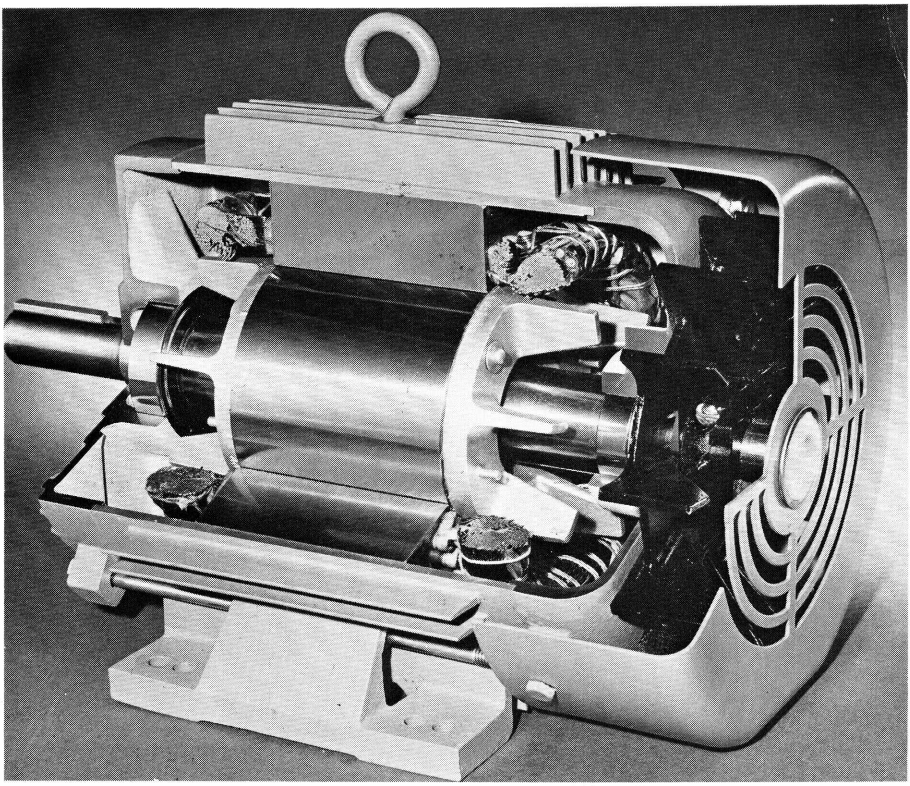


FIGURE 15.—Totally enclosed motors may be either nonventilated, disposing of heat by radiation, or fan cooled. This is a fan-cooled type.

or wet conditions or where explosive gas or dust mixtures are present.

Bearings

Electric motors are available with either sleeve bearings (fig. 16) or ball bearings (fig. 17). Operating conditions determine whether sleeve or ball bearings should be used. Sleeve-bearing motors usually are quieter and cost less than ball-bearing motors but generally require more maintenance.

Sleeve-bearing motors usually are designed to operate only in the horizontal position, although sleeve bearings are sometimes used in a vertical position in small motors. When sleeve bearings are lubricated with oil, the reservoir must always be toward the bottom of the motor.

Ball-bearing motors may be operated in either a horizontal or vertical position and are better suited for end thrust and control of end play than sleeve-bearing motors. Ball bearings that are normally used in electric motors are designed to absorb some thrust, but if the thrust load is high, special thrust bearings must be used. Also, enclosed motors

that are used in wet and dirty conditions usually have ball bearings.

Motor Ratings

Motors of a given horsepower rating are built in a certain size of frame or housing. For standardization, NEMA has assigned the frame size to be used for each integral horsepower motor so that shaft heights and dimensions will be the same to allow motors to be interchanged.

Motors designed after 1964 are commonly called T-rate motors. These motors are smaller than older motors, which may cause some problems in replacement use.

The smaller size of T-rate motors is the result of closer design tolerances and better magnetic and insulating materials. Also,

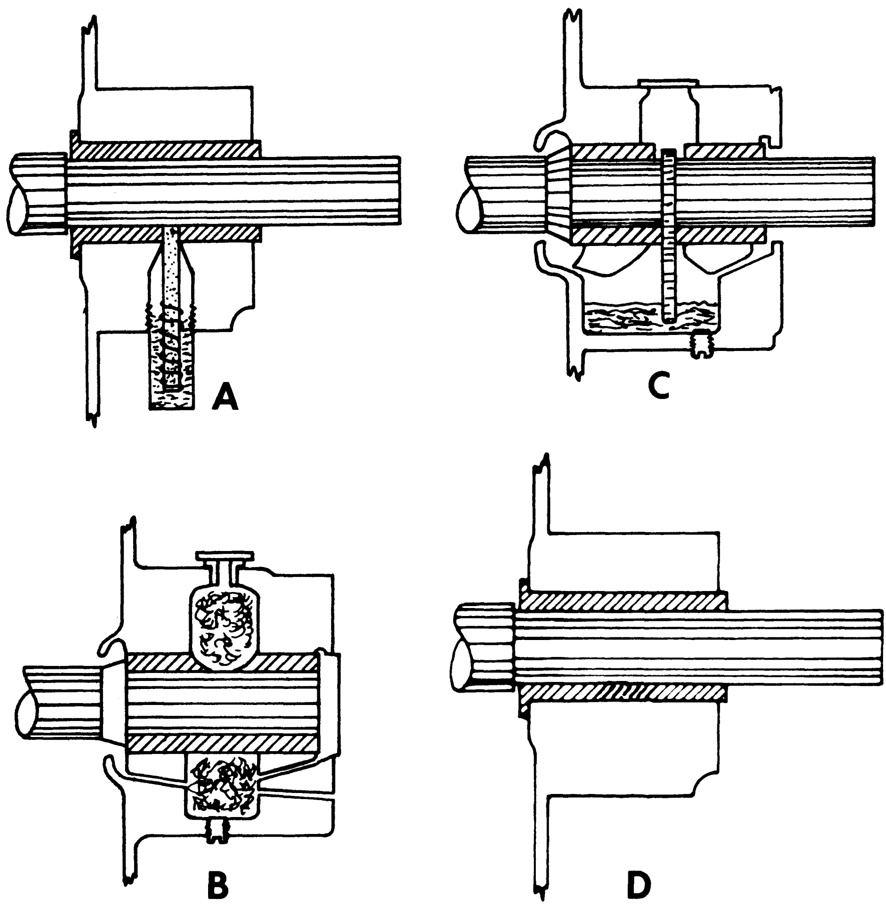


FIGURE 16.—Low-cost sleeve bearings are suitable for many motor applications. The motor shaft must be mounted horizontally with the oil reservoir underneath. Sleeve bearings will not absorb axial thrust. They may be lubricated by (A) oil wick, (B) yarn, (C) oil ring, or (D) impregnated permanent lubrication.

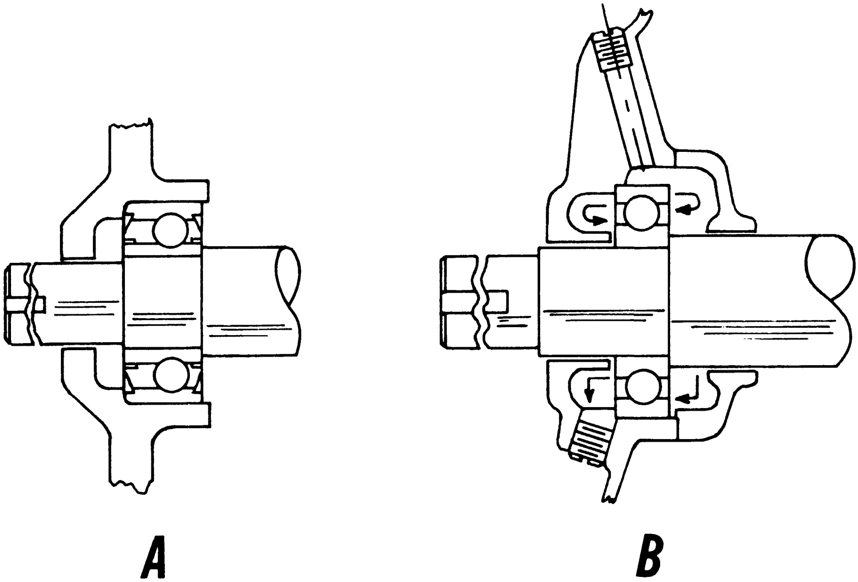


FIGURE 17.—A motor equipped with ball bearings may be mounted in any position. Ball bearings can take a small amount of axial thrust. Bearings may be either (A) the sealed type, requiring disassembly for relubrication, or (B) the type lubricated with a grease gun.

better insulation allows higher operating temperature within the motor, which makes the old rule no longer valid that you should be able to hold your hand on a motor for 10 seconds or more if the motor is not overheating.

Table 2 shows the motor frame sizes used for various sizes of integral horsepower motors. Shaft diameters for motors with a single straight shaft are shown in table 3. The shaft height of integral horsepower motors may be obtained by dividing the first two numbers of the frame size by 4. Example: The shaft height for the 200-frame-size series is 20 divided by 4, or 5 inches.

The shaft height of fractional horsepower motors may be obtained by dividing the frame size by 16.

Because of tighter design tolerances, the temperature rise of T-rate motors will stay within specifications only if the motor terminal voltage is kept within plus or minus 10 percent of the nameplate rating. The motor winding temperature will exceed specifications and motor life will be shortened unless the specified range of motor terminal voltage and load are maintained.

Motors are designed for continuous or limited duty. Those designed for continuous duty will deliver the rated horsepower for an indefinite period of time without overheating. General-purpose

Table 2.—Motor frames for various sizes of 1,800–r.p.m. motors[1]

Kind and size of motor	Motor-frame sizes (NEMA frame series)							
	140	180	200	210	220	250	280	320
	Horsepower							
Single-Phase T-Rate (after 1964)	1 1½	2 3		5 7½				
Single-Phase, U-Rate (1952 to 1964)		1 1½		2 3		5 7½		
Three-Phase, T-Rate (after 1964)	1 1½ 2	3 5		7½ 10		15 20	25 30	40 50
Three-Phase, U-Rate (1952 to 1964)		1 1½ 2		3 5		7½ 10	15 20	25 30
Three-Phase (pre-1952)			1 1½		2 3	5	7½	10 15

[1] The information for this table was taken from NEMA tables MG 1-13.01, 1-13.02, 1-13.01a, and 1-13.02a (1968).

motors should always be the continuous-duty type.

Limited-duty motors will deliver rated horsepower for a specified period of time but cannot be operated continuously at the rated load. A typical use of a limited-duty motor is as a silo unloader. A limited-duty motor will operate the unloader satisfactorily for a short period and it costs less than a continuous-duty motor. However, if the operating period is extended, the limited-duty motor will overheat and may burn out prematurely.

Motor nameplates carry the essential information regarding a motor's characteristics. A typical nameplate is shown in figure 18. The information generally given on the nameplate includes the following:

Frame and type.—The NEMA designation for frame designation and type.

Horsepower—The horsepower rating of the motor.

Motor code.—Designated by a letter indicating the starting current required. The higher the locked - rotor kilovolt - ampere (kva), the higher the starting current surge. Table 4 shows the most common letter designations and the locked-rotor kva they represent.

Cycles, or hertz.—The frequency at which the motor is designed to be operated.

Phase.—The number of phases on which the motor operates.

Revolutions per minute (r.p.m.)—The speed of the motor at full load.

Voltage.—The voltage or voltages of operation.

Thermal protection.—An indication of thermal protection provided for the motor, if it is provided.

Amps.—The rated current (amperes) at full load.

Time.—Time rating of the

Table 3.—Shaft diameter for foot-mounted electric motors with a single straight shaft extension[1]

Motor frame size	Shaft diameter inches
143, 145	¾
143T, 145T, 182, 184	⅞
182T, 184T, 213, 215	1⅛
213T, 215T, 254U, 256U	1⅜
254T, 256T, 284TS, 286TS, 284U, 286U, 324S, 326S	1⅝
284T, 286T, 324TS, 326TS, 324U, 326U, 364US, 364TS, 365US, 365TS	1⅞
324T, 326T, 364U, 365U	2⅛
364T, 365T	2⅜

[1] The information for this table was taken from NEMA tables MG1-11.31 and MG1-11.31a.

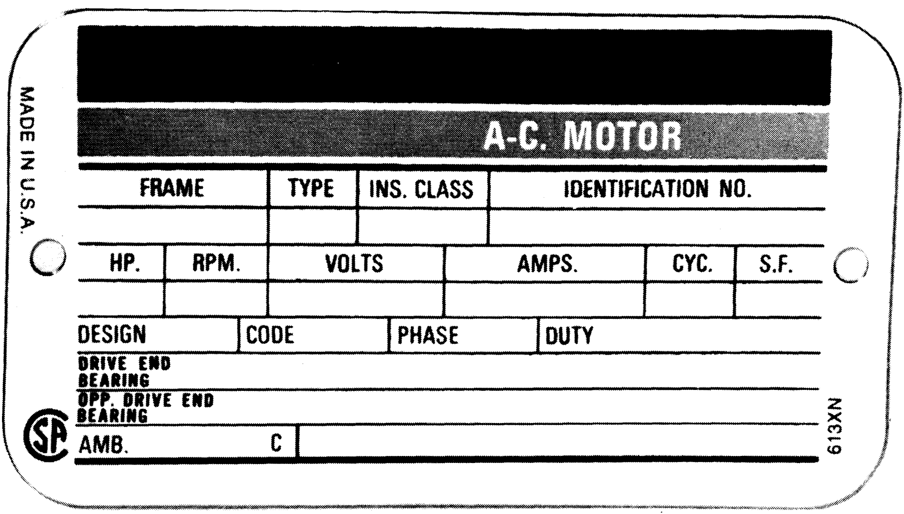


FIGURE 18.—The motor nameplate gives motor characteristics. The code designation, service factor, time rating, and temperature rise are important considerations in selecting a motor for a given job.

Table 4.—Motor code letters usually applied to ratings of motors normally started on full voltage[1]

Code letter	Locked rotor[2] kva per horsepower	Horsepower sizes	
		Single-phase	Three-phase
F	5.0 to 5.6		15 up
G	5.6 to 6.3	5	7½ to 10
H	6.3 to 7.1	3	5
J	7.1 to 8.0	1½ to 2	3
K	8.0 to 9.0	¾ to 1	1½ to 2
L	9.0 to 10.0	½	1

[1] The information for this table was taken from NEMA table MG 1-10.37.

[2] Locked rotor kva is equal to the product of line voltage times motor current divided by 1,000 when the rotor is not allowed to rotate; this corresponds to the first power surge required to start the motor. Locked-rotor kva per horsepower range includes the lower figure up to but not including the higher figure.

motor showing the duty rating as continuous or as a specific period of time the motor can be operated.

Ambient temperature, or temperature rise.—The maximum ambient temperature at which the motor should be operated, or the temperature rise of the motor above the ambient air at rated load.

Service factor.—The amount of overload that the motor can tolerate on a continuous basis at rated voltage and frequency.

Insulation class.—A designation of the insulation system used, primarily for convenience in rewinding.

NEMA design.—A letter designation for integral horsepower motors specifying the motor characteristics.

In addition, the bearing designations are often given on the nameplate for both ends of the shaft for convenience in replacement.

Generally a motor with a continuous-duty rating and a 40° C. (72° F.) temperature rise is a good motor capable of operating satisfactorily for an indefinite period of time if properly serviced and operated under normal conditions. However, with the development of improved insulating materials, it is possible to have general-purpose motors which will operate at a rise of 70° C. (158° F.) or more above ambient temperature.

INSTALLATION AND WIRING

Proper installation of an electric motor is essential for satisfactory operation, maximum service, and personal safety. The installation and wiring should conform to the recommendations of the National Electrical Code (NEC) and to any local code that has more restrictive requirements.

Causes of Motor Failure

Motors properly selected and used give many years of satisfactory service. Failures are most often due to overheating, moisture, bearing failure, or starting mechanism failure. Preventive maintenance and proper motor loading are the best insurance against motor failure. Motor life is prolonged by keeping the motor cool, dry, clean, and lubricated.

Overheating.—Heat is one of the most destructive agents causing premature motor failure. Overheating occurs because of motor overloading, low voltage at the motor terminals, excessive ambient temperatures, or poor cooling caused by dirt or lack of ventilation. If heat is not dissipated, insulation failure and possibly bearing failure can ruin a motor.

Moisture.—Moisture should be kept from entering a motor. The proper motor should be chosen for use in a damp environment and it should be covered to protect it from the weather, particularly during periods when it is not used.

Bearing failure.—Bearings should be kept properly lubricated. Bearings may fail in unused motors that are not rotated for extended periods, such as crop driers. Special care in lubrication may be required for these motors.

Starting mechanism failure.—Choice of a well-built motor will help solve this problem. Also, the starting mechanism must be kept free of dirt and moisture, the same as bearings and motor windings.

Mounting

Secure mounting and correct alignment with the load are essential for proper motor performance. The motor should be positioned where it is readily accessible, but not in the way. If possible, the motor should be located so that it will not be exposed to excessive moisture, dust, or abrasive material.

Mount the motor on a smooth, solid foundation and fasten the mounting bolts tightly. If mounted on an uneven base or fastened insecurely, the motor may become misaligned with the load during operation. This will throw unnecessary strain on the frame and bearings, causing rapid wear and overheating. Loose mounting also causes vibration and noise during operation.

Connecting to the Load

Motors may be connected to the load by direct drive, belt and pulley, or chain and sprocket.

Direct drive can be used only when the motor and the driven equipment operate at the same speed. A flexible coupling should be used, and the motor shaft and driven shaft should be in near perfect alignment. This prevents excessive wear of the shaft bearings.

Using a V-belt is the most common and the easiest way of connecting a motor to the load.

High-speed chain drives are

used when a positive drive is necessary or when the torque required is more than a V-belt drive can transmit.

Proper belt tension must be maintained. If a belt is too loose, it will slip on the drive pulley, overheat, and wear out quickly. If it is too tight, it will cause the belt and bearings to wear excessively.

To properly tension a V-belt drive, measure the span between shafts as shown in figure 19. Measure the force required to deflect the belt 1/64 inch for each inch of span. The force required should be within the values shown in table 5 for the type of belt used.

Most motors available for farm use operate at about 1,800 r.p.m. Equipment generally operates at much slower speeds. Provision for the required load speed can be made by using the proper size pulley on the driven equipment in relation to the motor pulley. To determine the load-pulley size, multiply the speed of the motor by the diameter of the motor pulley, then divide by the speed of the driven equipment.

Example.—

A load needs to run at 600 r.p.m. The driving motor operates at 1725 r.p.m. and has a 6-inch diameter pulley.

$$\text{Equipment pulley diameter} = \frac{\text{motor speed} \times \text{motor pulley diameter}}{\text{equipment speed}}$$

$$\text{Equipment pulley diameter} = \frac{1{,}725 \times 6}{600} = 17.25 \text{ in.}$$

The motor pulley and equipment pulley must be correctly aligned to avoid excessive wear of the belt and bearings (fig. 20). Pulley alignment can be checked by laying a straight ruler along the outside edge of the pulleys (fig. 21).

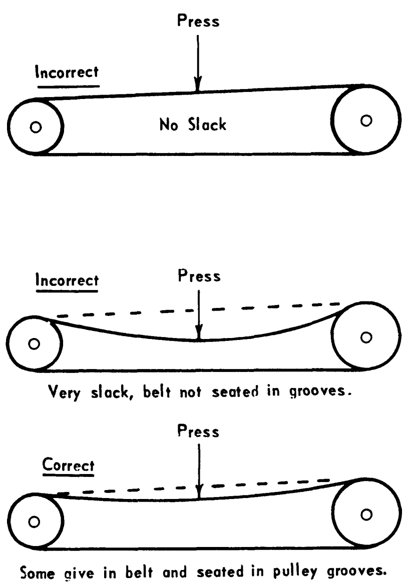


FIGURE 19. Adjust V-belt tension correctly.

Wiring

For safety, a good ground should be provided to the frame of all electric motors. If an electrical fault develops in the motor or wiring, the ground will prevent hazardous voltages from appearing on the motor frame.

Motors perform best at rated voltage and when adequate wiring is provided to the motor.

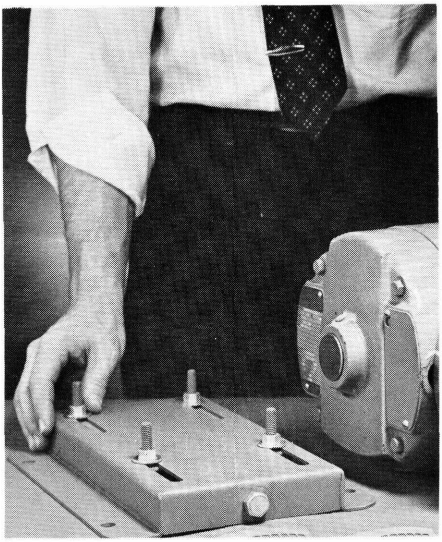


FIGURE 20.—A slotted motor base provides a convenient method for aligning the motor with the load and for adjusting the belt tension.

125 percent of the full-load current of the motor.

When conductors supply more than one motor on a single circuit, the wire size is determined by taking a current value of 125 percent of the full-load current of the largest motor plus 100 percent of the current for each additional smaller motor.

The following measures must be provided for in the wiring to motors:

(1) Branch-circuit overcurrent protection to protect the conductors of the motor circuit.

(2) A means to disconnect the motor from the electrical supply.

(3) Motor overcurrent protection to prevent overloading the motor under running conditions.

Operating motors with a terminal supply voltage within the range of rated voltage, and up to plus 10-percent of rated voltage, makes motors less subject to damage during reductions in power system voltage. Adequate voltage also provides better motor performance than that obtained at voltages below the nameplate rating.

Table 6 gives full-load currents of single-phase motors and table 7 gives full-load currents of three-phase motors. Current values shown in these tables should be used for wire size selection unless the motor nameplate current is larger; in that case, use the nameplate current value. Branch-circuit conductors to an individual motor should be selected to carry

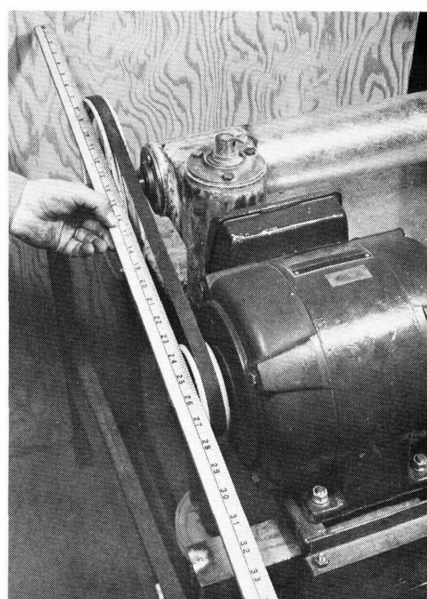


FIGURE 21.—Align the motor and load pulleys so that the belt is perpendicular to each shaft.

Table 5.—Recommended deflection force for V-belt tensioning[1]

V-belt cross section	Small sheave diameter range	Small sheave r.p.m. range	Speed ratio range	Deflection force	
				Minimum	Maximum
type	*inches*			*pounds*	*pounds*
A	3.0 to 3.2		2.0 to 4.0	2.3	3.2
	3.4 to 3.6		2.0 to 4.0	2.5	3.6
	3.8 to 4.2		2.0 to 4.0	2.9	4.2
	4.6 to 7.0		2.0 to 4.0	3.5	5.1
B	4.6		2.0 to 4.0	4.0	5.9
	5.0 to 5.4		2.0 to 4.0	4.5	6.7
	5.6 to 6.4		2.0 to 4.0	5.0	7.4
	6.8 to 9.4		2.0 to 4.0	5.8	8.6
C	7.0		2.0 to 4.0	7.1	10.0
	7.5 to 8.0		2.0 to 4.0	7.9	11.0
	8.5 to 10.0		2.0 to 4.0	9.3	13.0
	10.5 to 16.0		2.0 to 4.0	11.0	16.0
D	12.0 to 13.0		2.0 to 4.0	16.0	24.0
	13.5 to 15.5		2.0 to 4.0	18.0	27.0
	16.0 to 22.0		2.0 to 4.0	21.0	31.0
E	21.6 to 24.0		2.0 to 4.0	33.0	47.0
3V	2.5 to 3.5	1,200 to 3,600	2.0 to 4.0	3.0	4.3
	3.51 to 4.50	900 to 1,800	2.0 to 4.0	3.5	5.3
	4.51 to 6.0	900 to 1,800	2.0 to 4.0	4.3	6.0
5V	7.0 to 9.0	600 to 1,500	2.0 to 4.0	8.8	13.0
	9.1 to 12.0	600 to 1,200	2.0 to 4.0	9.5	14.0
	12.1 to 16.0	400 to 900	2.0 to 4.0	11.0	15.0
8V	12.5 to 17.0	400 to 900	2.0 to 4.0	22.0	31.0
	17.1 to 24.0	200 to 700	2.0 to 4.0	23.0	34.0

[1] Pressure must be applied at midspan perpendicular to the belt. Example: For a span of 32 inches, the measured deflection should be 1/64 × 32, which is ½ inch. For a Type A belt with a small sheave diameter of 3 inches, the pressure to produce the ½-inch deflection should be 2.3 to 3.2 pounds.

(4) A controller to stop and start the motor.

Wire Sizes

Tables 8 to 11 show the required wire size for copper and aluminum conductors for single-phase motors and a 2-percent voltage drop. Tables 12 and 13 show equivalent information for three-phase motors. To prevent low voltage from causing improper motor operation, wiring should be selected to limit the voltage drop under full-load conditions to 2 percent for branch circuits and to a total voltage drop of 5 percent for the branch circuit and service wiring combined.

Connections

Single-phase, single-speed motors usually have from two to six leads. The number of leads depends on the type of motor and

Table 6.—Full-load currents for single-phase a.c. motors[1]

Motor horse-power	115 volts Full load	115 volts 125% full load	230 volts Full load	230 volts 125% full load
	amps	*amps*	*amps*	*amps*
1/6	4.4	5.5	2.2	2.8
1/4	5.8	7.2	2.9	3.6
1/3	7.2	9.0	3.6	4.5
1/2	9.8	12.2	4.9	6.1
3/4	13.8	17.2	6.9	8.6
1	16.0	20.0	8.0	10.0
1½	20.0	25.0	10.0	12.5
2	24.0	30.0	12.0	15.0
3	34.0	42.0	17.0	21.0
5	56.0	70.0	28.0	35.0
7½			40.0	50.0
10			50.0	62.0

[1] To obtain full-load currents for 208-volt motors, increase corresponding 230-volt motor full-load current by 10 percent.

on whether it is a single- or dual-voltage unit.

Split-phase and capacitor motors that are single-voltage and are not reversible (the direction of rotation cannot be changed) have only two leads. Split-phase and capacitor motors that are single-voltage and are reversible have four leads—two for the main winding and two for the auxiliary, or starting, winding.

Dual-voltage capacitor motors have a minimum of six leads—four leads for the main winding and two for the auxiliary winding. For low-voltage operation, all windings are connected in parallel to the line. For high-voltage operation, the main windings are wired in series and the auxiliary winding is connected to the center leads of the main winding and to one of the supply lines.

The direction of rotation can be changed in split-phase or capacitor motors by reversing the electrical connections of either the main winding or the auxiliary winding to the line (fig. 22). The terminals may be located on a terminal board or brought out of the motor frame into a terminal box as numbered leads. The wiring diagrams for the specific motor that is being wired must be followed when making connections.

Repulsion-start induction motors and repulsion-induction

Table 7.—Full-load currents for three-phase a.c. motors[1]

Motor horse-power	Full load	125% full load
	amps	*amps*
1/2	2.0	2.5
3/4	2.8	3.5
1	3.6	4.5
1½	5.2	6.5
2	6.8	8.5
3	9.6	12.0
5	15.2	19.0
7½	22.0	28.0
10	28.0	35.0
15	42.0	52.0
20	54.0	68.0
25	68.0	85.0
30	80.0	100.0
40	104.0	130.0
50	130.0	162.0
60	154.0	192.0
75	192.0	240.0
100	248.0	310.0
125	312.0	390.0

[1] To obtain full-load currents for 208-volt motors, increase corresponding 230-volt full-load current by 10 percent.

Table 8.—Sizes of copper wire for single-phase, 115-120 volt motors and a 2-percent voltage drop[1]

Load in amps	Minimum allowable wire size			Length of wire to motor in feet													
	Wire in cable, conduit, or earth		Bare or covered wire overhead in the air[2]	20	30	40	50	60	80	100	120	160	200	250	300	400	500
	Types R,T,TW	Types RH, RHW, THW		Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
5	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
6	12	12	10	12	12	12	12	12	12	12	12	10	8	8	8	6	4
7	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
9	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
10	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
12	12	12	10	12	12	12	12	12	10	8	8	6	6	4	4	3	2
14	12	12	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
16	12	12	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
18	12	12	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
20	12	12	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
25	10	10	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
30	10	10	10	12	10	8	8	8	6	4	4	3	2	1	1	00	000
35	8	8	10	12	10	8	8	6	6	4	4	3	2	1	0	00	000
40	8	8	10	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
50	6	6	10	10	8	6	6	4	4	3	2	1	0	00	000	0000	250
60	4	6	8	8	8	6	4	4	3	2	2	0	00	000	000	250	300
70	4	4	8	8	6	6	4	4	3	2	1	0	00	000	0000	300	350

[1] Use 125 percent of motor nameplate current for single motors.
[2] The wire size in overhead spans must be at least number 10 for spans up to 50 feet and number 8 for longer spans.
[3] AWG is American wire gauge and MCM is thousand circular mil.

Table 9.—Sizes of aluminum wire for single-phase, 115-120 volt motors and a 2-percent voltage drop[1]

Load in amps	Minimum allowable wire size: Wire in cable, conduit, or earth: Types R,T,TW	Minimum allowable wire size: Wire in cable, conduit, or earth: Types RH, RHW, THW	Minimum allowable wire size: Bare or covered wire overhead in the air[2]	Length of wire to motor in feet: 20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
5	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
6	12	12	10	12	12	12	12	12	10	10	10	8	6	6	6	4	3
7	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
9	12	12	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
10	12	12	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
12	12	12	10	12	12	10	10	10	8	6	6	4	4	3	3	1	0
14	12	12	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
16	10	10	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
18	10	10	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
20	10	10	10	12	10	8	8	6	6	4	4	3	2	1	0	00	000
25	10	10	10	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
30	8	8	10	10	8	6	6	6	4	3	3	1	0	00	00	0000	250
35	6	8	10	10	8	6	6	4	4	3	2	1	0	00	000	0000	300
40	6	8	10	8	6	6	4	4	3	2	1	0	00	000	0000	250	300
50	4	6	8	8	6	4	4	3	2	1	0	00	000	0000	250	300	400
60	2	4	6	6	6	4	3	3	1	0	0	000	0000	250	300	350	500
70	2	2	6	6	4	4	3	2	1	0	00	000	0000	300	350	500	600

[1] Use 125 percent of motor nameplate current for single motors.
[2] The wire size in overhead spans must be at least number 10 for spans up to 50 feet and number 8 for longer spans.
[3] AWG is American wire gauge and MCM is thousand circular mil.

Table 10.—Sizes of copper wire for single-phase, 230-240 volt motors and a 2-percent voltage drop[1]

Load in amps	Minimum allowable wire size: Wire in cable, conduit, or earth: Types R,T,TW	Wire in cable, conduit, or earth: Types RH, RHW, THW	Bare or covered wire overhead in the air[2]	Length of wire to motor in feet: 20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
2	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	10
4	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	10	10
5	12	12	10	12	12	12	12	12	12	12	12	12	12	12	10	10	8
6	12	12	10	12	12	12	12	12	12	12	12	12	12	10	10	8	8
8	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6
10	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
12	12	12	10	12	12	12	12	12	12	12	12	10	8	8	8	6	4
14	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
17	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
20	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
25	10	10	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
30	10	10	10	12	12	12	10	10	8	8	8	6	4	4	4	2	1
35	8	8	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
40	8	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
45	6	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
50	6	6	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
60	4	6	8	12	10	8	8	8	6	4	4	3	2	1	1	00	000
70	4	4	8	12	10	8	8	6	6	4	4	3	2	1	0	00	000
80	2	4	6	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
100	1	3	6	10	8	6	6	4	4	3	2	1	0	00	000	0000	250

[1] Use 125 percent of motor nameplate current for single motors.
[2] The wire size in overhead spans must be at least number 10 for spans up to 50 feet and number 8 for longer spans.
[3] AWG is American wire gauge and MCM is thousand circular mil.

Table 11.—Sizes of aluminum wire for single-phase, 230-240 volt motors and a 2-percent voltage drop[1]

Load in amps	Minimum allowable wire size: Wire in cable, conduit, or earth: Types R,T,TW	Minimum allowable wire size: Wire in cable, conduit, or earth: Types RH, RHW, THW	Minimum allowable wire size: Bare or covered wire overhead in the air[2]	Length of wire to motor in feet: 20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
2	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	10
3	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	10	8
4	12	12	10	12	12	12	12	12	12	12	12	12	12	10	10	8	8
5	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6
6	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
8	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
10	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
12	12	12	10	12	12	12	12	12	10	10	10	8	6	6	6	4	3
14	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
17	10	10	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
20	10	10	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
25	10	10	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
30	8	8	10	12	12	10	8	8	6	6	6	4	3	2	2	0	00
35	6	8	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
40	6	8	10	12	10	8	8	6	6	4	4	3	2	1	0	00	000
45	4	6	10	12	10	8	8	6	6	4	4	3	2	1	0	00	000
50	4	6	8	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
60	2	4	6	10	8	6	6	6	4	3	3	1	0	00	00	0000	250
70	2	2	6	10	8	6	6	4	4	3	2	1	0	00	000	0000	300
80	1	2	6	8	6	6	4	4	3	2	1	0	00	000	0000	250	300
100	0	1	4	8	6	4	4	3	2	1	0	00	000	0000	250	300	400

[1] Use 125 percent of motor nameplate current for single motors.
[2] The wire size in overhead spans must be at least number 10 for spans up to 50 feet and number 8 for longer spans.
[3] AWG is American wire gauge and MCM is thousand circular mil.

Table 12.—Sizes of copper wire for three-phase, 230-240 volt motors and a 2-percent voltage drop[1]

Load in amps	Minimum allowable wire size: Wire in cable, conduit, or earth — Types R,T,TW	Wire in cable, conduit, or earth — Types RH, RHW, THW	Bare or covered wire overhead in the air[2]	20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Length of wire to motor in feet — Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
2	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
4	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	10
5	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	10	10
6	12	12	10	12	12	12	12	12	12	12	12	12	12	12	10	10	8
8	12	12	10	12	12	12	12	12	12	12	12	12	12	10	10	8	8
10	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6
12	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
15	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
20	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
25	10	10	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
30	10	10	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
35	8	8	10	12	12	12	10	10	8	8	8	6	4	4	4	2	1
40	8	8	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1

Table 12.—Sizes of copper wire for three-phase, 230-240 volt motors and a 2-percent voltage drop—continued

Load in amps	Minimum allowable wire size			Length of wire to motor in feet													
	Wire in cable, conduit, or earth		Bare or covered wire overhead in the air[2]	20	30	40	50	60	80	100	120	160	200	250	300	400	500
	Types R,T,TW	Types RH, RHW, THW		Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
45	6	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
50	6	6	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
60	4	6	8	12	10	10	8	8	6	6	4	4	3	2	1	0	00
70	4	4	8	12	10	8	8	8	6	4	4	3	2	1	1	00	000
80	3	4	6	12	10	8	8	6	6	4	4	3	2	1	0	00	000
100	1	3	6	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
120	0	1	4	10	8	6	6	4	4	3	2	1	0	00	000	0000	250
150	000	0	3	8	6	6	4	4	3	2	1	0	00	000	0000	250	300
180	0000	000	1	8	6	4	4	3	2	1	0	00	000	0000	250	300	400
210	250	0000	0	8	6	4	4	3	2	1	0	00	000	0000	250	350	500
240	300	250	00	6	4	4	3	2	1	0	00	000	0000	250	300	400	500

[1] Use 125 percent of motor nameplate current for single motors.
[2] The wire size in overhead spans must be at least number 10 for spans up to 50 feet and number 8 for longer spans.
[3] AWG is American wire gauge and MCM is thousand circular mil.

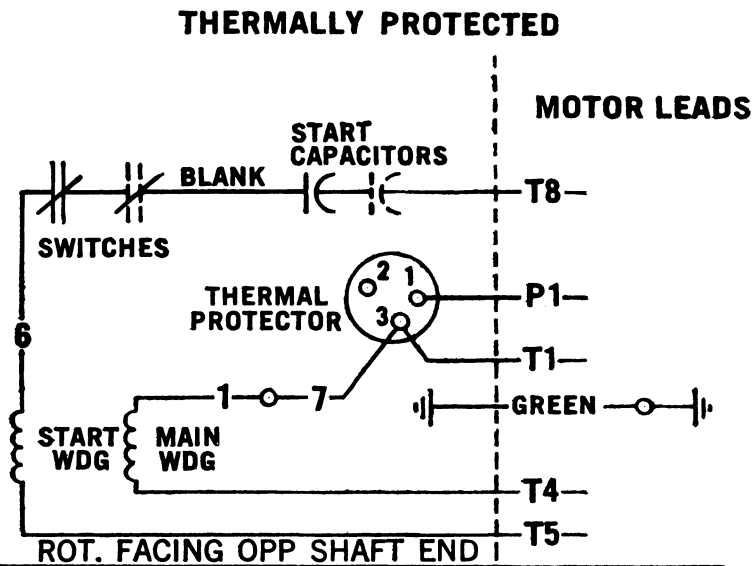
Table 13.—Sizes of aluminum wire for three-phase, 230-240 volt motors and a 2-percent voltage drop[1]—

Load in amps	Minimum allowable wire size: Wire in cable, conduit, or earth: Types R,T,TW	Minimum allowable wire size: Wire in cable, conduit, or earth: Types RH, RHW, THW	Minimum allowable wire size: Bare or covered wire overhead in the air[2]	Length of wire to motor in feet: 20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
2	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12
3	12	12	10	12	12	12	12	12	12	12	12	12	12	12	12	10	10
4	12	12	10	12	12	12	12	12	12	12	12	12	12	12	10	10	8
5	12	12	10	12	12	12	12	12	12	12	12	12	12	10	10	8	8
6	12	12	10	12	12	12	12	12	12	12	12	12	10	10	8	8	6
8	12	12	10	12	12	12	12	12	12	12	12	10	10	8	8	6	6
10	12	12	10	12	12	12	12	12	12	12	10	10	8	8	6	6	4
12	12	12	10	12	12	12	12	12	12	10	10	8	8	6	6	4	4
15	12	12	10	12	12	12	12	12	10	10	8	8	6	6	4	4	3
20	10	10	10	12	12	12	12	10	10	8	8	6	6	4	4	3	2
25	10	10	10	12	12	12	10	10	8	8	6	6	4	4	3	2	1
30	8	8	10	12	12	10	10	8	8	6	6	4	4	3	2	1	0
35	6	8	10	12	12	10	8	8	6	6	6	4	3	2	2	0	00
40	6	8	10	12	10	10	8	8	6	6	4	4	3	2	1	0	00
45	4	6	10	12	10	8	8	6	6	4	4	3	2	1	0	00	000

Table 13.—Sizes of aluminum wire for three-phase, 230-240 volt motors and a 2-percent voltage drop[1] continued

Load in amps	Minimum allowable wire size: Wire in cable, conduit, or earth: Types R,T,TW	Types RH, RHW, THW	Bare or covered wire overhead in the air[2]	Length of wire to motor in feet: 20	30	40	50	60	80	100	120	160	200	250	300	400	500
				Wire size (AWG or MCM)[3] (Note: Compare the size shown below with the size shown in the column to the left of the double line and use the larger size.)													
50	4	6	8	12	10	8	8	6	6	4	4	3	2	1	0	00	000
60	3	4	6	10	8	8	6	6	4	4	3	2	1	0	00	000	0000
70	2	3	6	10	8	6	6	6	4	3	3	1	0	00	00	0000	250
80	1	2	6	10	8	6	6	4	4	3	2	1	0	00	000	0000	300
100	0	1	4	8	6	6	4	4	3	2	1	0	00	000	0000	300	350
120	000	00	2	8	6	4	4	3	2	1	0	00	000	0000	250	350	400
150	0000	000	1	6	4	4	3	2	1	0	00	000	0000	250	300	400	500
180	300	0000	0	6	4	3	2	1	0	00	000	0000	250	300	350	500	600
210	350	300	00	6	4	3	2	1	0	00	000	0000	300	350	400	600	700
240	500	350	000	4	3	2	1	0	00	000	0000	250	350	400	500	700	800

[1] Use 125 percent of motor nameplate current for single motors.
[2] The wire size in overhead spans must be at least number 10 for spans up to 50 feet and number 8 for longer spans.
[3] AWG is American wire gauge and MCM is thousand circular mil.



ROT.	CONNECT LINE 1 TO	CONNECT LINE 2 TO	CONNECT TOGETHER
CCW	P1	T4, T5	T8, T1
CW	P1	T4, T8	T5, T1

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FIGURE 22.—The wiring diagram of a split-phase or capacitor motor shows which leads to interchange to reverse the direction of rotation.

motors usually are dual-voltage units with four winding leads. For low-voltage operation, the main windings are wired in parallel. For high-voltage operation, the windings are wired in series. No change in the rotor-brush connections is necessary for operation at either voltage.

Motors of the repulsion type can be reversed by rotating the brush ring to the alternate position (fig. 23). The brush ring of a repulsion motor is held in position by a locking screw or a spring clip. When released, the brushes may be rotated. The two brush positions are marked on the ring with an index on the frame. When the brush position is changed, the direction of rotation is reversed.

Special-purpose or special-duty, motors may differ in their wiring and method of reversing direction. Consult the manufacturer's instructions.

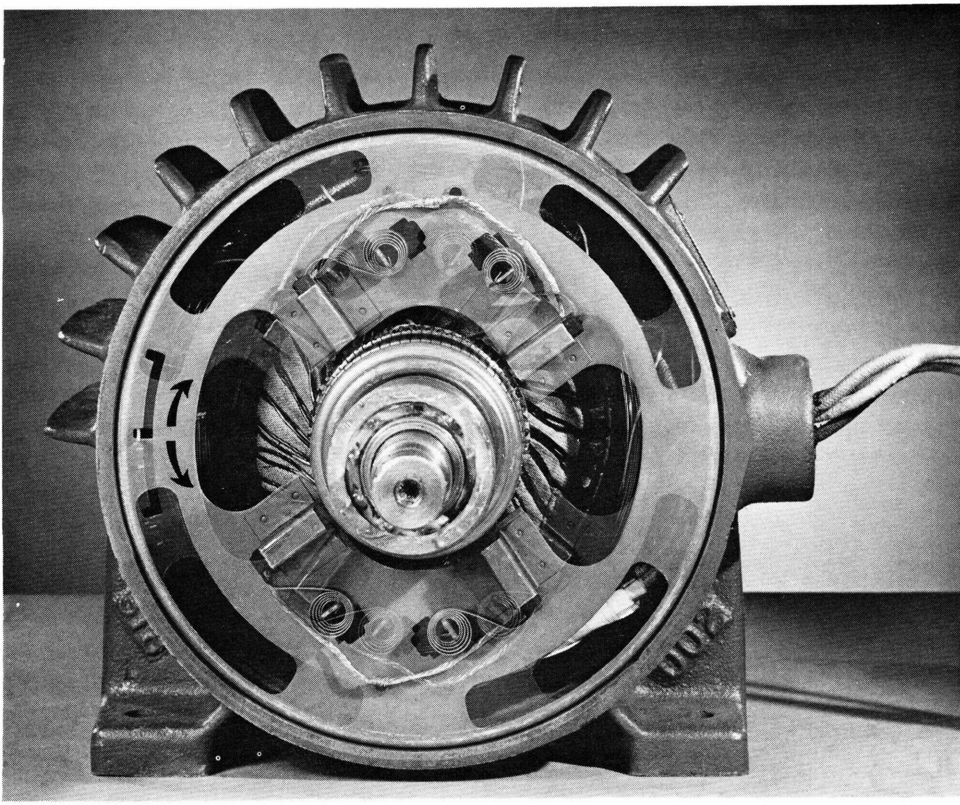

FIGURE 23.—Most repulsive-induction motors can be reversed by rotating the brush ring to the alternate position. The double arrow indicates rotation.

MOTOR PROTECTION AND CONTROL

Protection

Motors must be protected against both excessive current and excessive winding temperature caused by faults, overloads, or low supply voltage.

An overloaded motor draws excessive current from the line. This causes overheating that destroys the winding insulation and causes bearings to fail. Maximum temperature at which a motor can operate depends on its construction and the type of insulation used for the windings.

Motor current required for starting usually will be two to eight times that for running at full load. Short-circuit protection devices must be able to carry this high current for a short time.

Branch circuit fuses or circuit breakers do not adequately protect the motor; they primarily protect the circuit wires and give limited protection to the motor for short-circuit conditions only. Additional overcurrent protection for the motor is therefore needed.

Fuses

Time-delay fuses afford both short-circuit and overload protection (fig.24). Short circuits melt the fusible link in the fuse almost instantly, which breaks the circuit. For small continuous overloads, heat developed in the second element of the fuse weakens the eutectic solder connections, and permits a spring to break the connection (fig. 25). Time-delay fuses must be properly sized to protect the motor.

Other Overload Protective Devices

Motor starter switches, both manual and electromagnetic, are available with built-in overload protection. Thermal overload relays with either a bimetallic or eutectic element are a commonly used protective device (figs. 26 and 27).

If the overload relay elements are not thermally compensated, allowance must be made for ambient temperature. Your power supplier or electrician should be consulted for recommendations. The combination overload switch-relay unit should preferably be installed so it will be under the same operating conditions as the motor.

A thermal overload switch built into the motor affords the best protection against overload (fig. 28). The switch generally opens the line directly on fractional horsepower motors. With larger motors, a relay may be needed. Built-in thermal protective units may be automatic-reset or manual-reset types. The manual-reset unit is usually recommended for general-purpose use because the cause of the overload can be corrected before the motor is restarted and unexpected startup of equipment is avoided.

Overcurrent protection in the ungrounded conductor is adequate for single-phase motors. Overcurrent protection, however, should be provided in all three conductors supplying a three-

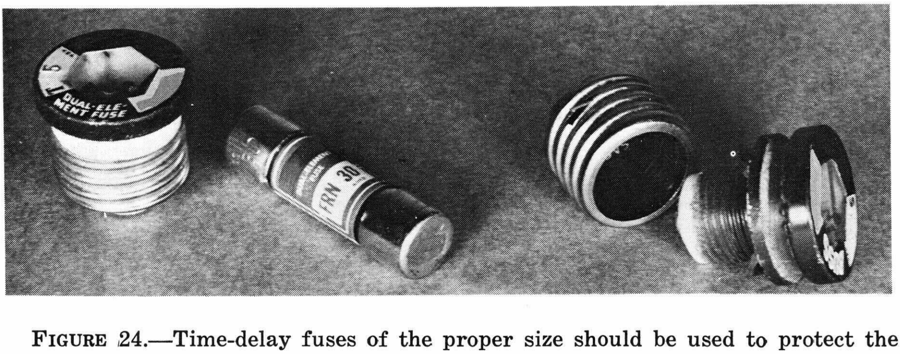

FIGURE 24.—Time-delay fuses of the proper size should be used to protect the motor circuits. The fuse on the left can replace a common plug fuse on old installations. The middle fuse is a cartridge fuse that should be used in 230-volt circuits. The fuse on the right when placed in a fuse socket cannot be replaced with any fuse except one with equal rating.

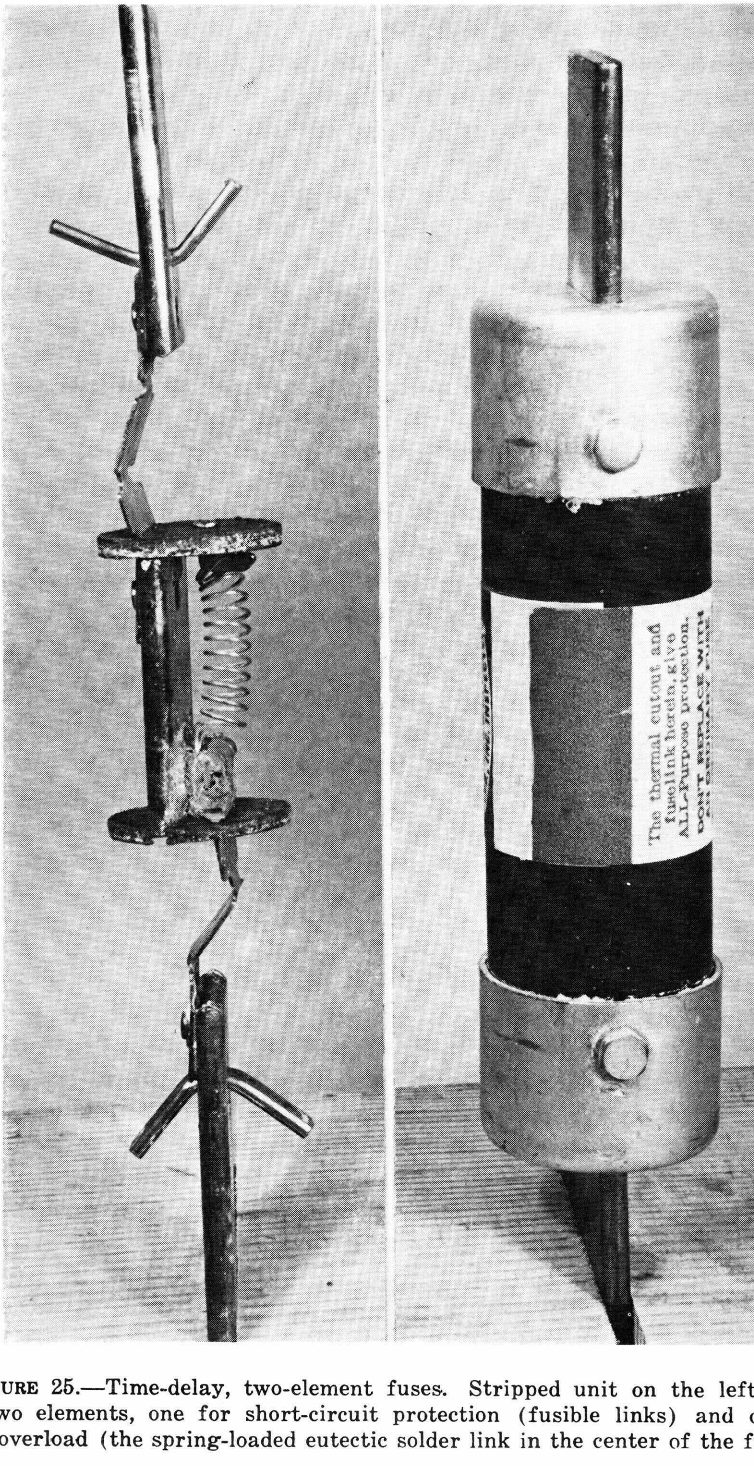

FIGURE 25.—Time-delay, two-element fuses. Stripped unit on the left shows the two elements, one for short-circuit protection (fusible links) and one for brief overload (the spring-loaded eutectic solder link in the center of the fuse).

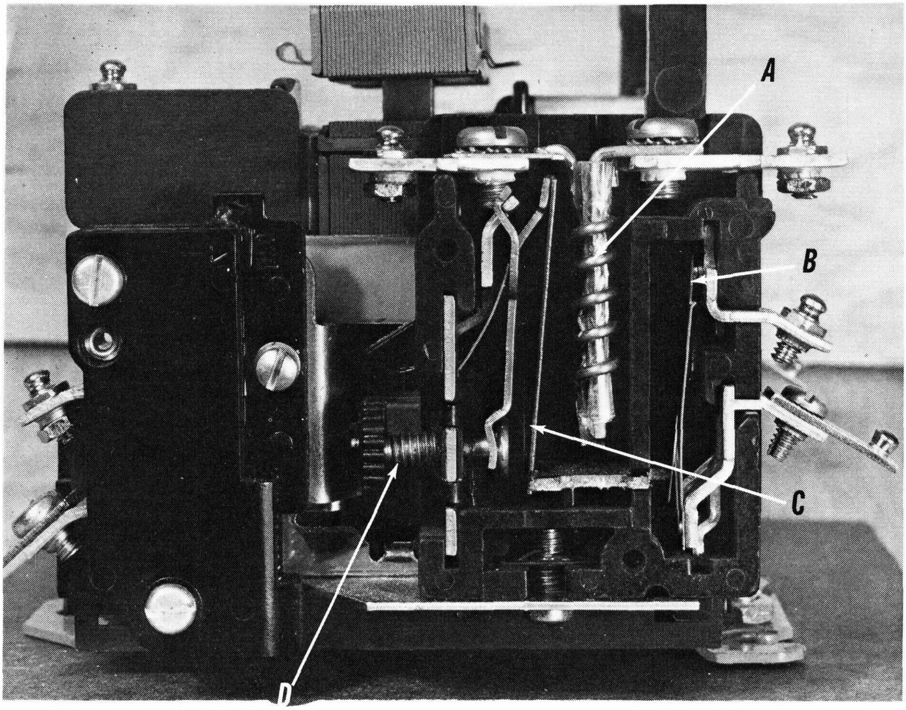

FIGURE 26.—The thermal overload relay may be the bimetallic type (shown here) or the eutectic solder type. This relay is the protective device most often used for manual and electromagnetic starter switches. (A) heater; (B) interlock contacts; (C) bimetallic strip; (D) compensation adjustment.

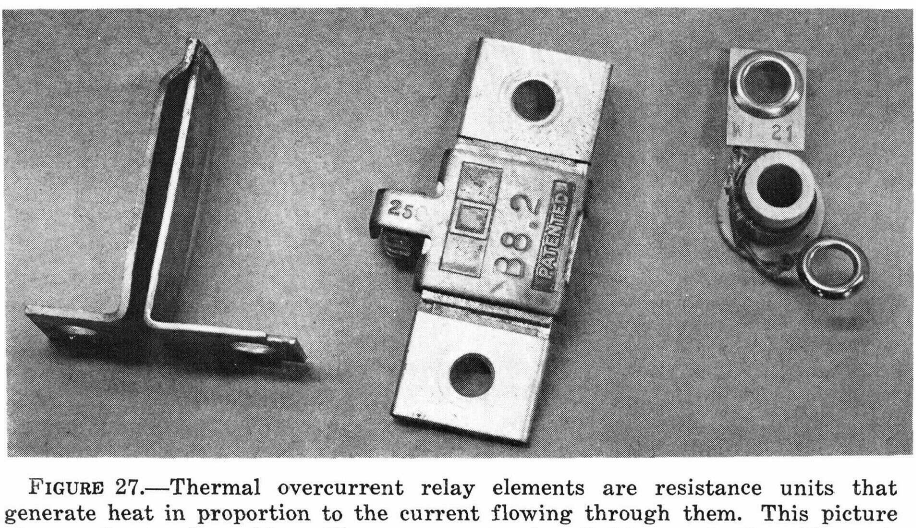

FIGURE 27.—Thermal overcurrent relay elements are resistance units that generate heat in proportion to the current flowing through them. This picture shows a heater for a bimetallic overcurrent relay (left), a eutectic solder unit (middle), and a heater (right). These are used in small manual starter switches.

phase motor to insure protection for all fault conditions.

The overcurrent device should be rated or selected to trip at no more than the following percent of motor full-load current rating:

(1) Motors with a service factor of 1.15 or greater—125 percent.

(2) Motors with a marked temperature rise of not over 40° C.—125 percent.

(3) All other motors — 115 percent.

Where these values cannot be matched exactly with standard sizes or settings, higher ratings or settings may be used, but they must not exceed the following percentages of motor full-load current rating:

(1) Motors with a service factor of 1.15 or greater—140 percent.

(2) Motors with a marked temperature rise not over 40°C.—140 percent.

(3) All other motors — 130 percent.

The values listed are maximum. Better protection will be afforded the motor if values are chosen at

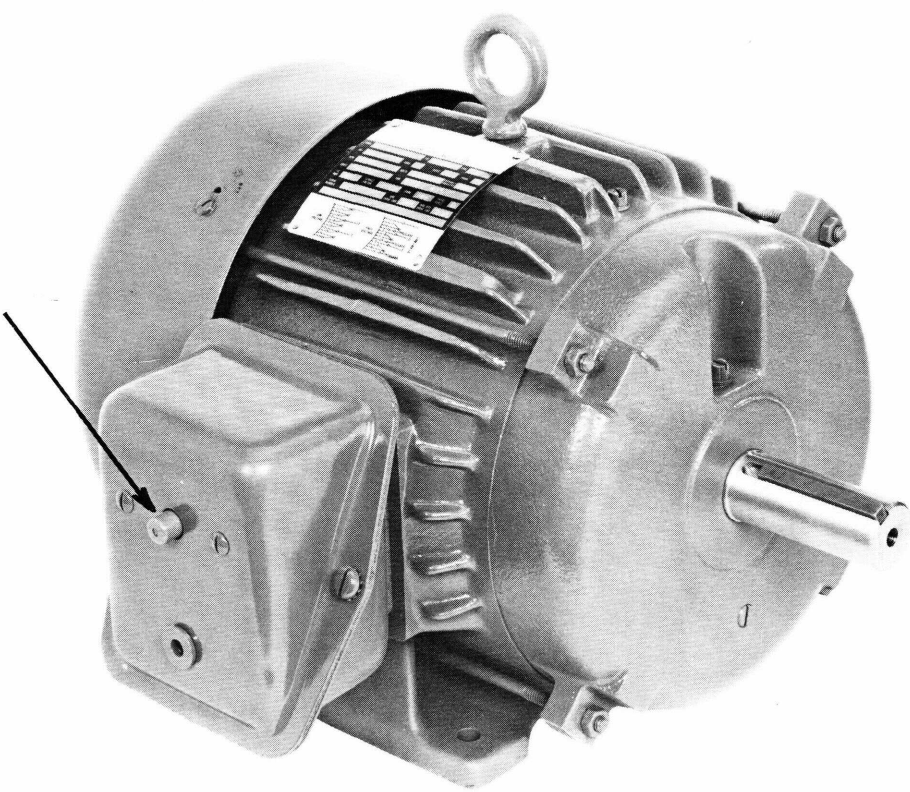

FIGURE 28.—A thermal overload switch built into the motor is an excellent method of protecting it from overload conditions. The arrow points to the reset button.

nameplate current rating or less. Most overcurrent devices will pass currents exceeding their rating for extended periods without tripping.

Controls

Controls for electric motors vary from a simple on-off toggle switch to complex automatic systems. Motor controls have two purposes: (1) start and stop the motor and (2) protect the motor from damage caused by excessive current. Only simple controls are discussed in this bulletin. Advice on more complex systems should be obtained from your local electrician or power supplier.

Manually Operated Switches

Manual switches are used most often to control small motors of one-half horsepower or less. These switches are low-cost devices. They are available with a built-in overcurrent cut-out that can be sized to the current demand of a particular motor. If the switch does not provide overcurrent protection, these motors must be provided with a suitable overload device such as a dual element fuse, sized specifically to protect the motor, or by a thermal overload built into the motor. Typical manual switch motor-control circuits are shown in figure 29.

Control switches for electric motors must be able to withstand the high starting current and the arcing that occurs when the circuit is opened (fig. 30). Quick-make, quick-break switches equipped with arc quenchers are

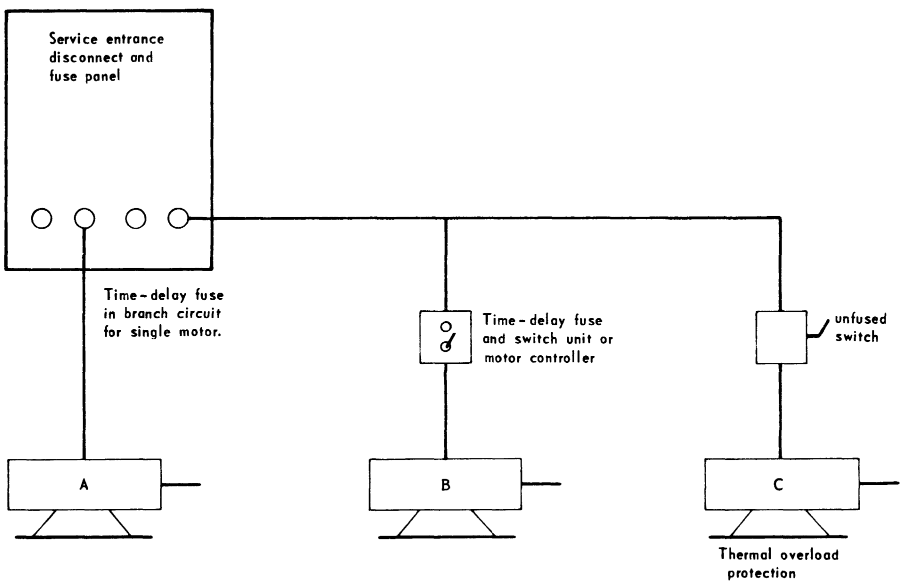

FIGURE 29.—Typical manual-switch, motor-control circuits.

used. These are rated by horsepower and voltage.

T-rated, tumbler-type light switches should not be used to control electric motors. They can withstand the high starting current but are not equipped with arc quenchers and usually burn out quickly.

Magnetic Motor Starters

A magnetic motor starter is the best kind to use for controlling a motor. This type starter should be used for all motors larger than one horsepower and is essential in automatic control systems. A magnetic coil allows operation from either local or remote locations and will remove the motor from the line if there is a loss of power. Built-in thermal or other type overload elements provide overcurrent protection for the motor and should be sized for the specific motor controlled.

There are many ways to connect the control circuits of magnetic motor starters. A commonly used circuit for a 230-volt single-phase motor is shown in figure 31. A more complex circuit is shown in figure 32, which provides a sequenced start for three motors. Simultaneous stopping of all motors is provided and overload contacts are interlocked to provide shutdown of all motors if any one of the motors is shut down because of overload.

Generally, motors should not be allowed to restart automatically after a loss of power. If automatic operation is necessary, provision should be made for random restarting to prevent the excessive voltage drop in the wiring that would occur if all motors came on at one time. This can be

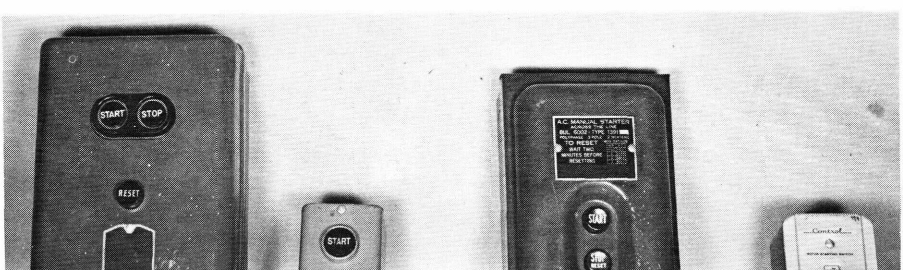

FIGURE 30.—The correct motor starter switch provides the best protection for your motor. From left, a magnetic motor starter with self-contained push-button switches; a push-button start-and-stop station for remote installation with a magnetic starter; a manual starter switch for integral-horsepower motors; and a manual switch for fractional-horsepower motors.

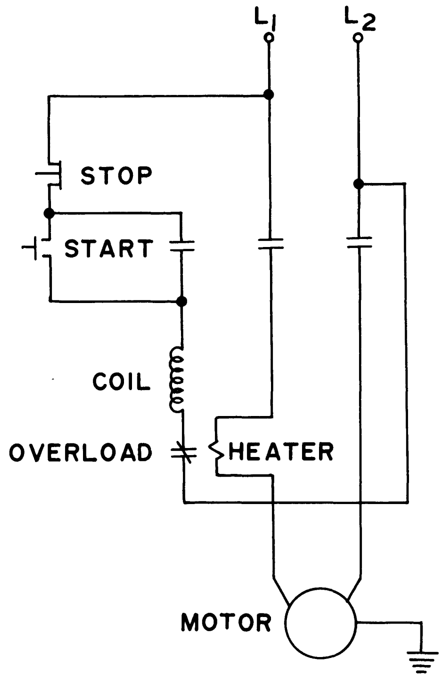

FIGURE 31.—Single-phase motor starter circuit with 240-volt holding cell.

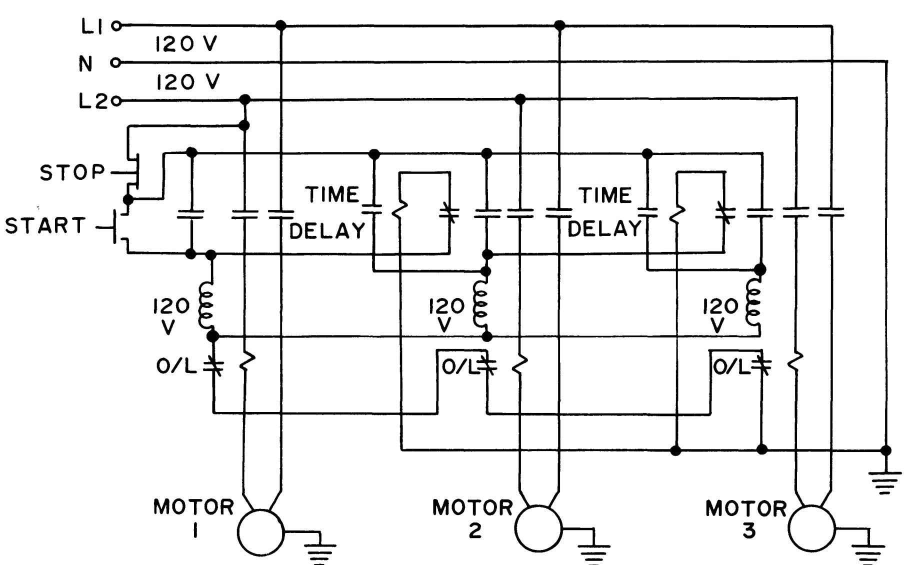

FIGURE 32.—Sequenced motor starting circuit with instantaneous stopping of all motors and interlocked overload relays.

accomplished by including a low-cost time-delay relay in the magnetic motor starter-control starter as shown in figure 33. This random restart feature is especially desirable for large-horsepower motors, such as those often found in crop-drying fans.

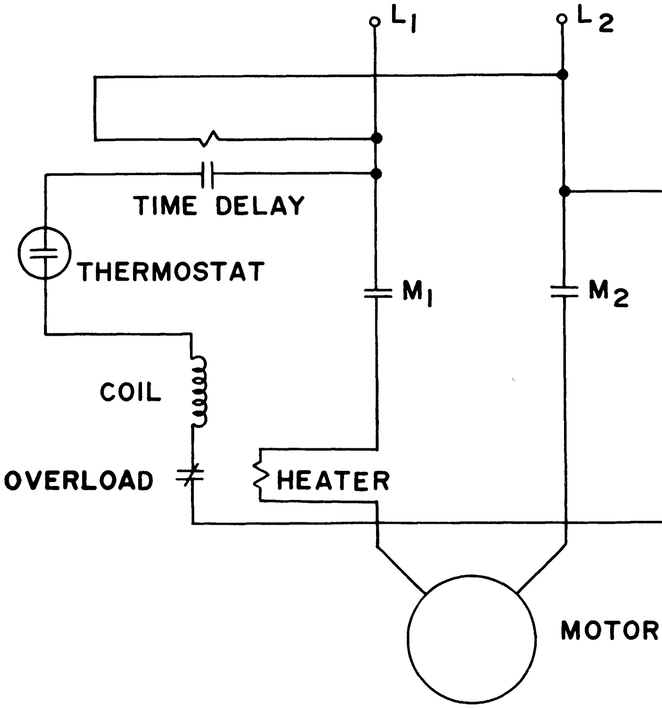

FIGURE 33.—Circuit for random restarting of motors under automatic control after a loss of power.

SERVICING AND REPAIRS

A well-made and properly installed electric motor requires less maintenance than many other types of equipment. However, for the best and most economical performance, periodic servicing is required.

The service operations listed should be performed at least once a year or more often if the motor operates under severe heat, cold, or dust conditions.

(1) Remove dust and dirt from the air passages and cooling surfaces of the motor to insure proper cooling. Plugged air passages of an open motor, or a coating of dust on a totally enclosed motor, will cause the motor to overheat under normal operation.

(2) Check bearings for wear. Excessive side or end play may cause the motor to draw higher than normal starting current, de-

velop less starting torque, and may damage the motor.

(3) Make sure the motor shaft turns freely. Tight or misaligned bearings will cause the motor to overheat.

(4) Lubricate the motor according to the manufacturer's specifications. Do not overlubricate. Too much lubricant is as bad as too little.

(5) Check all wiring for frayed or bare spots. Repair or replace as needed.

(6) Clean the starting-switch contacts of split-phase and capacitor motors and the commutator and brushes in wound-rotor (repulsion-type) motors. Use very fine sand paper; *do not use emery cloth.*

(7) Replace worn brushes and make sure the brush-lifting and shorting-ring action works smoothly in wound-rotor motors.

(8) Check belt pulleys to be sure they are secure on their shafts. Align the belts and pulleys carefully. Improper alignment causes excessive wear on belts and pulleys. Check and adjust belt tension. Replace belts that are badly worn.

Properly installed and maintained electric motors should give trouble-free service for many years. Occasionally, however, a motor may give trouble or fail to operate. Some repairs require the services of an experienced electrician or motor serviceman; others can be made by the operator.

Table 14 lists some common motor troubles, their causes, and the methods of repair. Table 15 gives additional information for troubles peculiar to wound-rotor motors.

Caution: Do not attempt to service or repair an electric motor until it has been disconnected from the circuit.

Table 14.—Common motor troubles and repairs

Cause	Remedy
Motor Fails To Start	
Fuses blown, switch open, broken or poor connections, or no voltage on line.	Check for proper voltage at motor terminals. Examine fuses, switches, and connections between motor terminals and points of service. Look for broken wires, bad connections, corroded fuse holders. Repair or replace as necessary.
Defective motor windings.	Locate and repair.[1]
Motor Hums But Will Not Start	
Starting winding switch does not close.	Clean or replace and lubricate if needed.
Defective starting capacitor.	Replace.[1]
Open rotor or stator coil.	Locate and repair.[1]
Motor overloaded.	Lighten load. Check for low voltage.
Overloaded line or low voltage.	Reduce electrical load. Check wiring. Increase wire size. Notify power company.
Bearings worn so that rotor rubs on starter.	Replace bearings. Center rotor in stator bore.[1]
Bearings too tight or lack of proper lubrication.	Clean and lubricate bearings. Check end bells for alignment.
Burned or broken connections.	Locate and repair.
Motor Will Not Start With Rotor In Certain Position	
Burned or broken connections; open rotor or stator coil.	Inspect, test, and repair.[1]
Motor Runs But Then Stops	
Motor overloaded.	Lighten motor load. Check for low voltage.
Defective overload protection.	Locate and replace.[1]
Slow Acceleration	
Overloaded motor.	Lighten motor load.
Poor connections.	Test and repair.
Low voltage or overloaded line.	Lighten line load. Increase size of line wire.[1]
Defective capacitor.	Replace.[1]

See footnote at end of table.

Table 14.—Common motor troubles and repairs—continued

Cause	Remedy
Excessive Heating	
Overloaded motor.	Reduce motor load.
Poor or damaged insulation; broken connections; or grounds or short circuits.	Locate and repair.[1]
Wrong connections.	Check wiring diagram of motor.
Worn bearings or rotor rubs on stator.	Renew or repair bearings. Check end bell alignment.[1]
Bearings too tight or lack of proper lubrication.	Clean and lubricate bearings. Check end bell alignment.
Belt too tight.	Slacken belt.
Motor dirty or improperly ventilated.	Clean motor air passages.
Defective capacitor.	Replace.
Excessive Vibration	
Unbalanced rotor or load.	Rebalance rotor or load.
Worn bearings.	Replace.[1]
Motor misaligned with load.	Align motor shaft with load shaft.
Loose mounting bolts.	Tighten.
Unbalanced pulley.	Have pulley balanced or replaced.
Uneven weight of belt.	Get new belt.
Low Speed	
Overloaded.	Reduce load.
Wrong or bad connections.	Check for proper voltage connections and repair.
Low voltage, overloaded line, or wiring too small.	Reduce load. Increase size of wire.[1]

[1] These repairs should be made by an experienced electrician.

Table 15.—Common motor troubles and repairs that are peculiar to wound-rotor motors

Cause	Remedy
Motor Fails To Start	
Worn brushes.	Renew brushes.
Brushes stuck in holder.	Adjust brushes.[1]
Brushes not properly set.	Check with marks on frame.
Slow Acceleration	
Dirty or rough commutator.	Clean and sandpaper.
Worn or stuck brushes.	Renew or adjust.[1]
Brushes not set properly.	Adjust brushes.[1]
Low Speed	
Dirty or rough commutator	Clean and sandpaper.[1]
Badly worn brushes.	Replace with new brushes.[1]
Brushes not properly set.	Adjust brushes.[1]
Brushes stuck.	Clean and adjust.
Excessive Sparking When Starting	
Dirty or rough commutator.	Clean and sandpaper.[1]
Worn or stuck brushes	Renew or adjust brushes.[1]
High or low commutator bars.	Turn off in lathe.[1]
Excessive sparking at one place on commutator.	Check for shorted rotor winding or loose winding to bar connection.[1]
High mica.	Undercut mica.[1]
Overloaded.	Lighten load.
Open rotor or stator coil, grounds, or poor connections.	Inspect, test, and repair.[1]
High or low voltage.	Check size of wiring. Notify power company.
Excessive Sparking At Normal Speed	
Dirty short-circuiting device.	Clean with acceptable solvent; do not use carbon tetrachloride.
Governing mechanism sticks or is badly adjusted.	Readjust mechanism.[1]
Worn brushes.	Replace.

Table 15.—Common motor troubles and repairs that are peculiar to wound-rotor motors—continued

Excessive Speed	
Cause	**Remedy**
Dirty short-circuiting device.	Clean with acceptable solvent; do not use carbon tetrachloride.
Governing mechanism sticks or is badly adjusted.	Readjust mechanism.[1]
Rapid Brush Wear	
Rough commutator.	Smooth with fine (00) sandpaper. Do not use emery cloth.
High or low bars.	Turn off in lathe.[1]
High mica.	Undercut mica.[1]
Overload.	Lighten motor load.
Poor connections.	Test and repair.
Low voltage.	Increase size of wire.[1]
Commutator not round.	Test and repair.[1]

[1] These repairs should be made by an experienced electrician.

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